

ENGINEERING GEOLOGICAL  
ROADING AGGREGATE INVESTIGATIONS  
OF THE WAKATIPU BASIN

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A thesis  
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Access Road to Queenstown - Lakes District  
Council Aggregate Quarry.

## ABSTRACT

The Wakatipu Basin lies within the Otago Schist belt, and aggregates derived from the schist do not meet New Zealand basecourse specifications. This study comprises engineering geological investigations of the roading aggregate with the objective of identifying potential aggregate source areas which comply with specifications.

Five aggregate sources, two glacial and three post-glacial, have been identified, and their geology related to aggregate quality.

A survey of existing aggregate quarries confirmed the sub-specification quality of schist derived roading aggregate, and that the highest quality roading aggregate of the Basin is produced from exotic glacial transported greywacke.

A greywacke rich aggregate source area of Kame terraces was investigated. Investigations included mapping at scales of 1:10 000 and 1:1 500, and the excavation of test pits.

A geotechnical testing programme concluded that the Kame terrace source area was capable of producing roading aggregate for basecourse, and is comparable with the highest quality roading aggregate of the Wakatipu Basin. Subsequently, the Queenstown - Lakes District Council has developed an aggregate quarry within the Kame terrace source area.

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## CHAPTER ONE

### INTRODUCTION

#### 1.1 PROJECT BACKGROUND

The Wakatipu Basin and Catchment lie on the north west side of the Otago Province (Fig. 1.1). For the purpose of this thesis study, the Wakatipu Basin is defined as the area that incorporates the Two Mile quarry, Frankton, Arrowtown, Arthurs Point, Queenstown, Glenorchy and Greenstone Station Roads (Fig. 1.2). The objective of the Wakatipu Basin definition is to restrict discussion of roading aggregate to the geographical limits of the Queenstown-Lakes District Council "aggregate survey" (discussed in section 1.4).

The Wakatipu Catchment is defined as the area that includes the catchments of the Shotover River, Arrow River and all rivers flowing into Lake Wakatipu (Fig. 1.2). The objective of the Wakatipu Catchment definition is to define the area which may influence the aggregates of the Wakatipu Basin.

Lake Wakatipu is fed by two major rivers, the Dart and the Rees, and is drained by the Kawarau River, a tributary of the Clutha. Lake Wakatipu is bounded by several mountain ranges, the Remarkables Range, Eyre Mountains, Richardson Mountains, Humboldt Mountains and the Thompson Mountains. All have approximate maximum elevations of 2000 m (Fig. 1.1).

Queenstown (population 4000) is a major tourist resort and rural servicing centre located within the Wakatipu Basin.

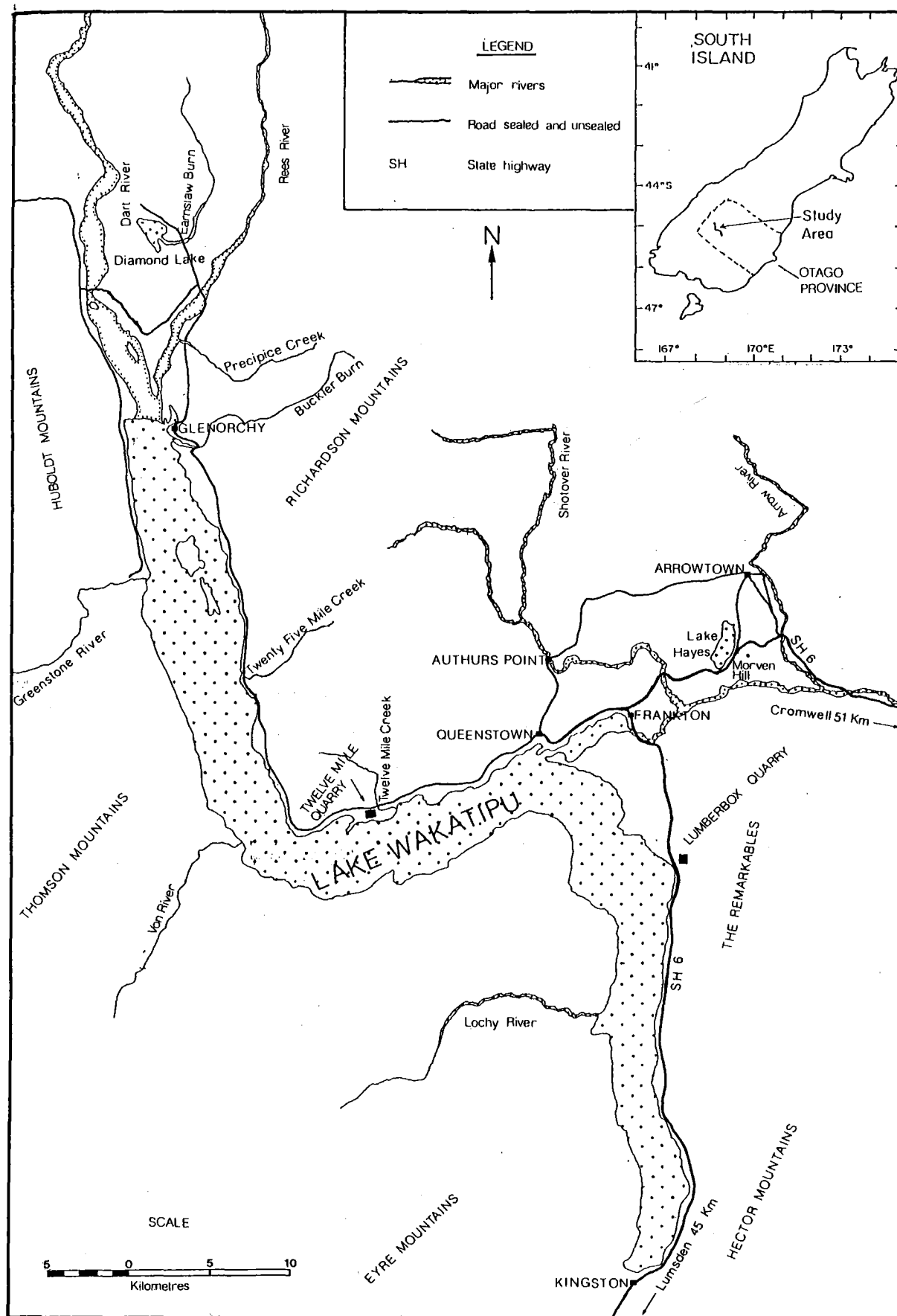


Fig. 1.1 Locality diagram.

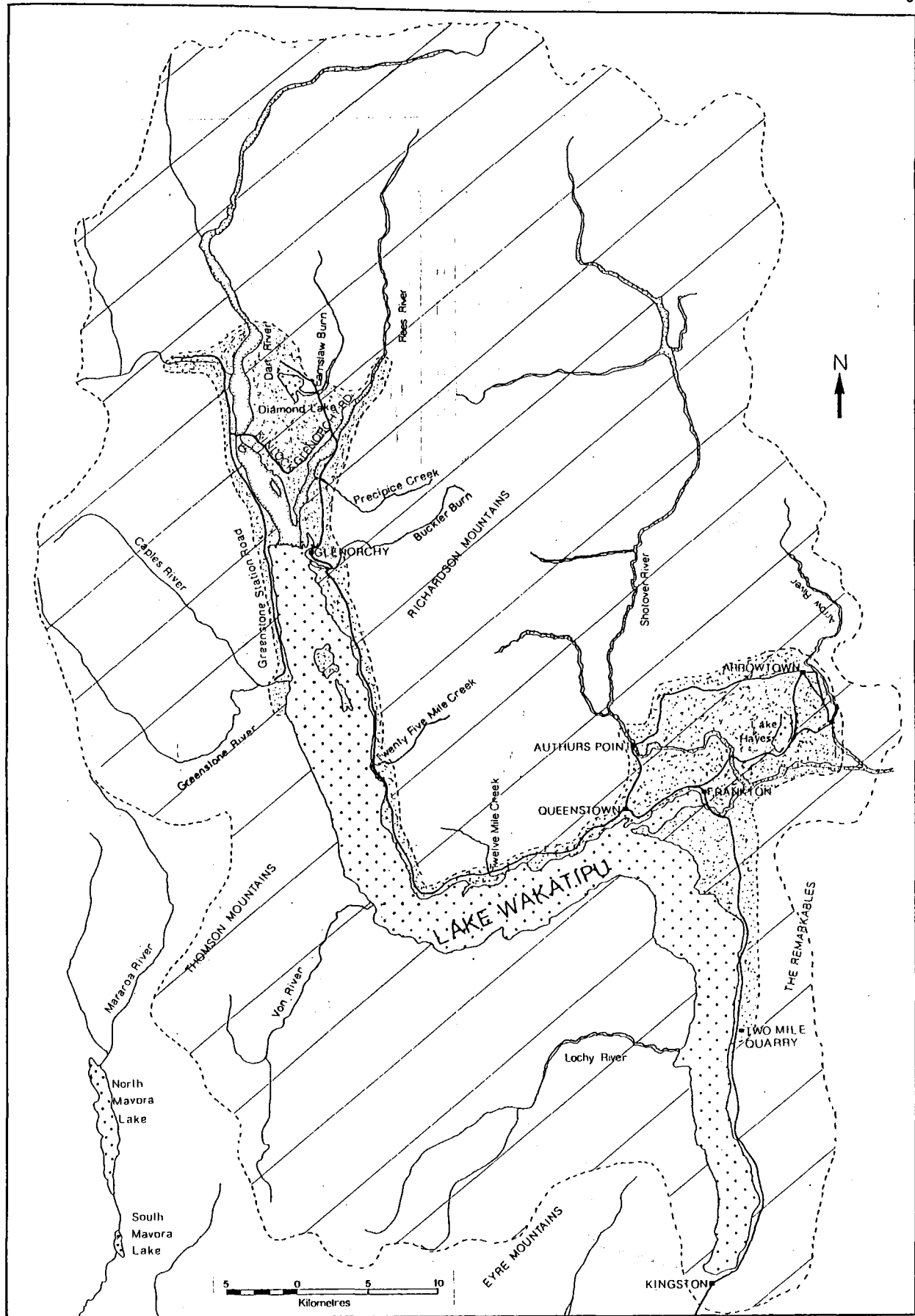


Fig. 1.2 Map showing area defined by the Wakatipu Basin (stippled) and the Wakatipu Catchment (cross hatched).



The majority of roading aggregate servicing Queenstown and the surrounding Wakatipu Basin is produced at the Lumberbox and Twelve Mile quarries (pers comm R. Duff, Queenstown-Lakes District County Engineer) (Fig. 1.1). Neither quarries comply with New Zealand standards controlling basecourse production, which are outlined in the National Roads Board (NRB) M/4 specification (Appendix 1), and roading aggregate of NRB M/4 quality has to be transported into the Wakatipu Basin.

Two types of roading aggregate occur within the Wakatipu Basin:-

(a) schist derived roading aggregate (e.g. from Twelve Mile Quarry); and

(b) mixed schist and Caples Group<sup>1</sup> (Coombs et al 1976) derived roading aggregate (e.g. from Lumberbox Quarry).

Skinner (1967) comments that the schists of Central and West Otago are not suitable for high quality roading aggregate because of the relative softness and cleaved condition of the schist. Schist-derived aggregates of the Wakatipu Basin also produce poor quality roading aggregates and fail to meet the crushing resistance (NZS 3111:1980 Section 14) requirement of the NRB M/4 standard. The poor quality is attributable to the inherent schistosity of the schist derived clasts.

Roading aggregate sources derived from a mixture of schist and greywacke produce a higher quality roading aggregate, with crushing resistance values of M/4 standard.

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1) Rocks of the Caples Group are typically non-schistose (Coombs et al 1976), and have different geotechnical properties to Otago Schists, therefore the term "greywacke" will be used to describe rocks of the Caples Group.

The additional strength of these aggregate sources is attributable to the strong non-schistose "greywacke". However, the schist and greywacke aggregate usually has sand equivalent values (NZS 4402 Part 1:1980 Test 7) lower than the NRB M/4 requirement (i.e. <40). The unsatisfactory values are related to the fluvio-glacial origin of the deposits.

Glacial silt, which occurs as lenses within the deposits and adheres to clasts, is difficult to remove during roading aggregate production, and results in sub-M/4 sand equivalent values. Low sand equivalent values do not affect the performance of this particular roading aggregate (Wathey 1984), hence the mixed schist and greywacke aggregate produce the highest quality roading aggregate within the Wakatipu Basin.

## 1.2 REGIONAL GEOLOGY

Within the Wakatipu Catchment two types of basement rocks outcrop, Otago Schist and Caples Group (Coombs et al 1976). Rocks of the Caples Group outcrop on the north west side of Lake Wakatipu (fig 1.3) and can generally be described as dominantly greywackes and argillites (Coombs et al 1976). The two basement rocks are of different metamorphic grades, the Caples Group rocks grading into the higher metamorphic equivalent the Otago Schists (Mackinnon 1983). Otago Schist can generally be described as dominantly quartzofeldspathic schists of the Chlorite metamorphic zone (Wood 1978).

Tectonic movements of the Kaikoura Orogeny (which started in the early Miocene) resulted in differential uplift of the basement, producing the "basin and range" topography of Central Otago. Tertiary sediments are poorly represented

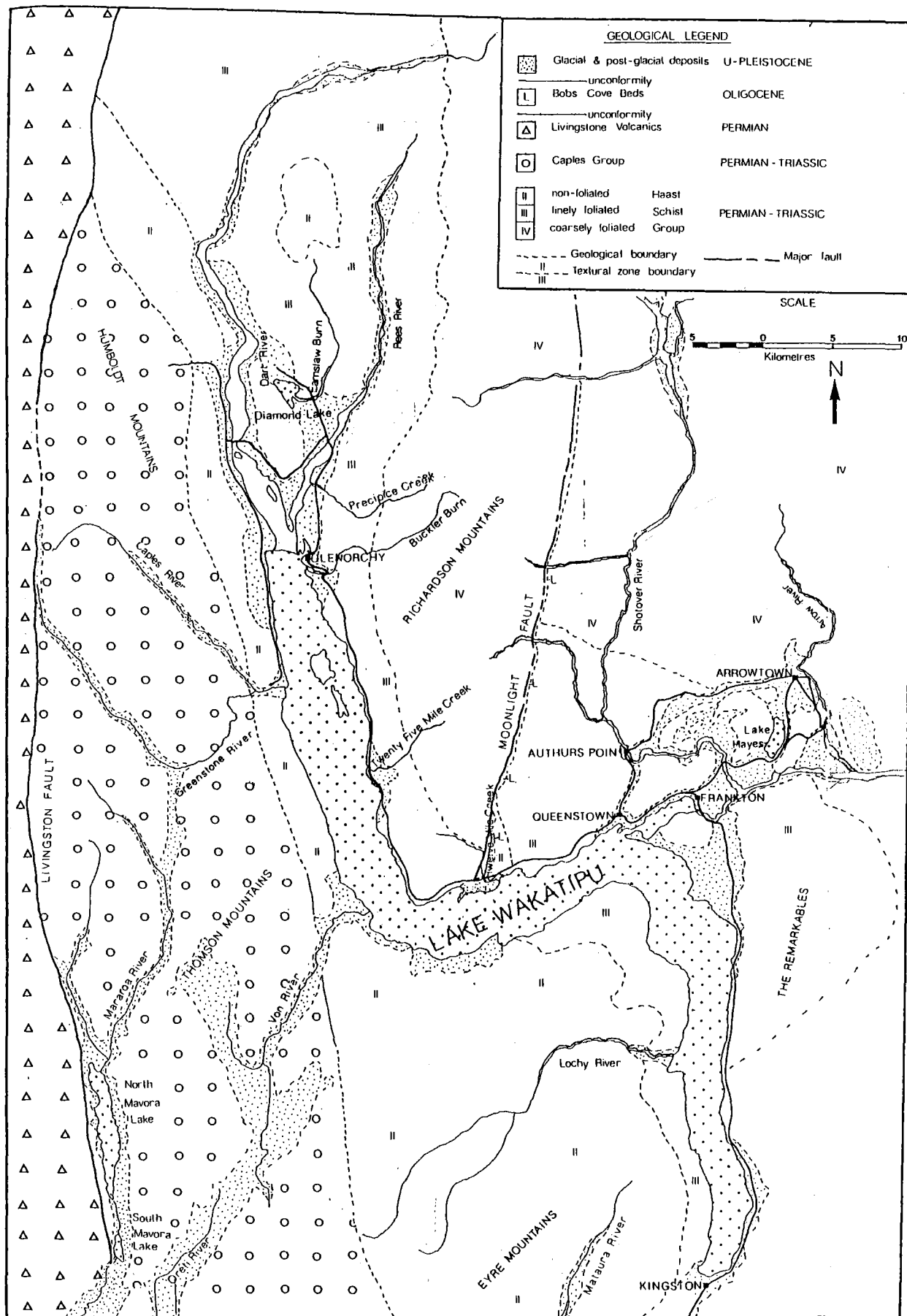


Fig. 1.3 Simplified geological map of the Wakatipu Catchment (after Wood 1962).

within the Wakatipu Catchment, with only minor amounts being preserved in down-thrown basins associated with the Moonlight Fault (Fig. 1.3). Sediments preserved are a sequence of marine breccia-conglomerate, siltstones and bioclastic limestone (Turnbull et al 1975).

Successive ice advances during the Pleistocene extensively modified the landscape, with the present geomorphology reflecting the glaciations, and in particular, the Last Glaciation which produced "freshly" glaciated topography and morainic deposits. Climatic warming at the end of the last glaciation produced a waning of the Wakatipu Glacier and the development of proto-Lake Wakatipu, which filled the "S" shaped depression and was dammed at Kingston by terminal moraine (Fig. 1.3). Episodic lake lowering is represented by post-glacial delta and fan deposits which occur around the periphery of Lake Wakatipu.

### 1.3 PREVIOUS AGGREGATE STUDIES

Previous work on roading aggregate in the Wakatipu Basin has been completed by Skinner (1967), Bell (1980), Wathey (1984), Bartley et al (1986) and Lindsay (1987). Skinner (1967) provides a general summary of the roading aggregate sources in the Otago and Southland districts. Bell (1980) evaluated the suitability of kame terrace material for use as a roading aggregate on The Remarkables Ski Field road. In a brief report, Wathey (1984) described the quality and quantity of existing aggregate resources of the Wakatipu Basin, and his report provides a useful summary of roading aggregate test results carried out by the Ministry of Works

and Development within the Wakatipu Basin.

Bartley (1986) described and discussed a NRB Road Research Project BC/53 on the Wakatipu Test Sections, the purposes of the project being to determine the cost effectiveness of using sub-M/4 standard roading aggregate from the Lumberbox quarry, and to monitor the performance of the roading aggregate. A brief report compiled by Lindsay (1987), evaluated the suitability of aggregate from the Farry quarry for basecourse production.

Outside the Wakatipu Catchment, aggregate investigations have been carried out for the Upper Clutha Development by Salt (1982) and Jacka (1985). The reports discuss the suitability of mixed schist and Torless Supergroup (ie. accumulation of greywacke and argillites) (Coombs et al 1976) for use as concrete aggregate.

#### 1.4 CURRENT AGGREGATE SURVEY

Roading aggregates in the Wakatipu Basin do not meet the NRB M/4 specifications, therefore suitable roading aggregate has to be transported into the Wakatipu Basin. The closest major source of NRB M/4 quality roading aggregate is at Lowburn, 60km east of Queenstown. However, Lowburn will be inundated by Lake Dunstan in 1989, therefore leaving the closest NRB M/4 quality aggregates at Maori Point and at Alexandra, both source areas are approximately 90km from Queenstown (Fig. 1.4).

On the 20th March 1986 the NRB advised the Queenstown Lakes District Council that no further aggregate from the Lumberbox Quarry (Fig. 1.1) would be available for any pri-

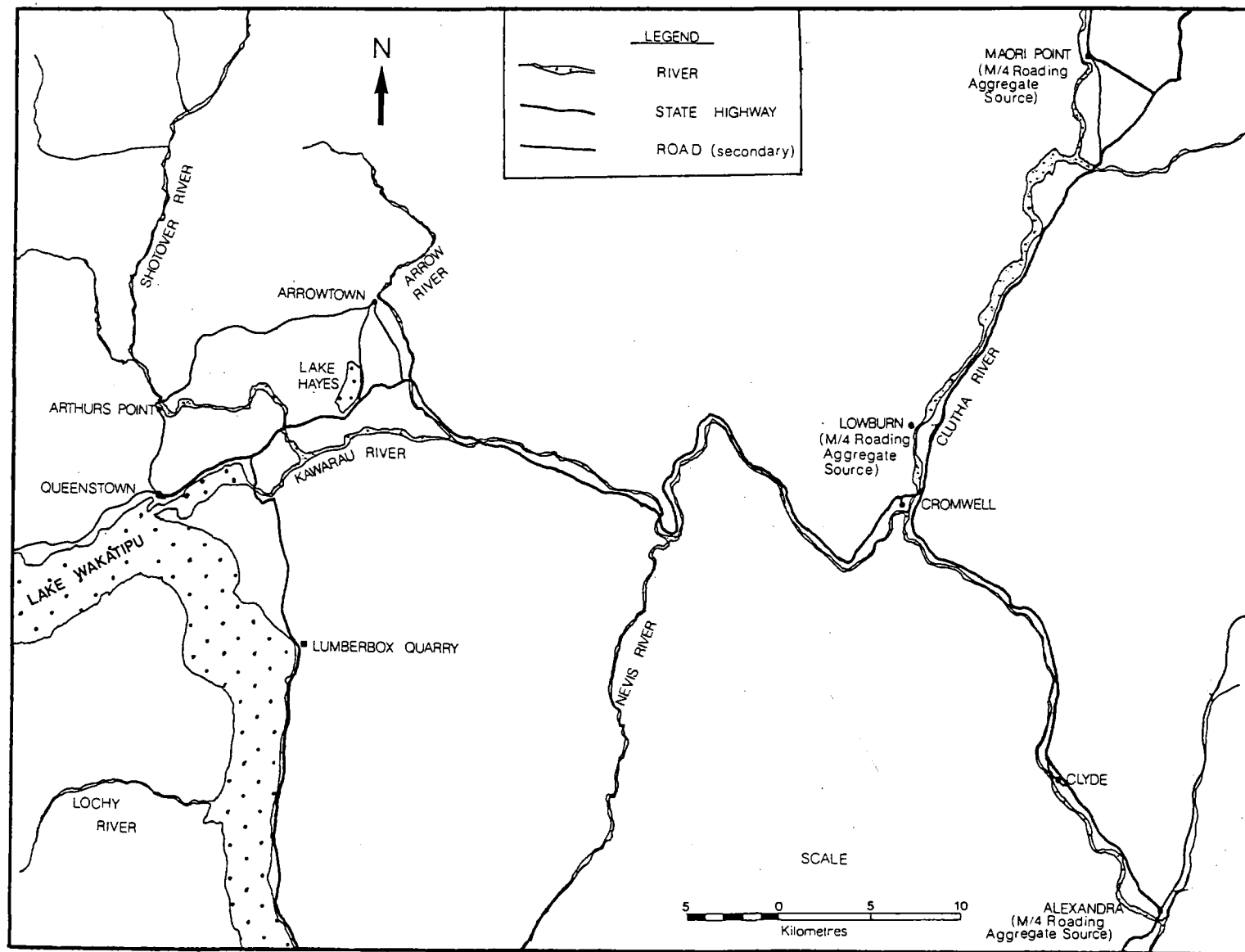


Fig. 1.4 NRB M/4 reading aggregate sources for the Wakatipu Basin.

vate work, including subdivision and development projects. On the 8 April 1986 Council adopted a similar policy to that of the NRB for the Twelve Mile Quarry (Fig. 1.1), this being considered necessary to conserve the limited supply of approximately two years (pers comm L Matchet, Queenstown-Lakes District Council County Clerk) of aggregate available, for Council use.

The restricted use of the Lumberbox and Twelve Mile quarries, combined with the limited life of the Twelve Mile quarry, has produced a shortage of quality roading aggregate within the Wakatipu Basin. This shortage of quality roading aggregate, combined with the high cost of transporting roading aggregate from a source outside the Wakatipu Basin, prompted the council to conduct an "aggregate survey" for quality sources within the Wakatipu Basin.

Council requested Duffill Watts and King (Consulting Engineers, Dunedin, Invercargill, Queenstown and Alexandra) to conduct the aggregate survey, and the author was employed to complete it. The aim of the survey was to locate aggregate sources capable of producing NRB M/4 AP40 quality aggregate within specified geographical limits; viz. (a) between the limits of the Lumberbox and Twelve Mile quarries, and (b) along the length of the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads (Fig.1.2). The limits of the aggregate survey were set by Council, and are based on Councils present and future roading aggregate requirements. The initial aggregate survey and additional work that was completed for the aggregate survey was then used, with Councils permission, as the basis for this thesis.

## 1.5 THESIS OBJECTIVES AND METHODOLOGY

### 1.5.1 Objectives

The thesis objectives are directly related to the aims of Councils aggregate survey.

The principal objectives of this thesis study are:

(1) to evaluate presently known aggregate resources of the Wakatipu Basin;

(2) to identify aggregate that is potentially capable of producing NRB M/4 AP40 quality roading aggregate within the specified geographical limits.

(3) to undertake engineering geological investigations to assess any such potential source areas; and

(4) to carry out a geotechnical testing programme to determine whether the potential aggregate source areas are in fact capable of producing NRB M/4 roading aggregate.

### 1.5.2 Methodology

#### (i) Field Work Programme

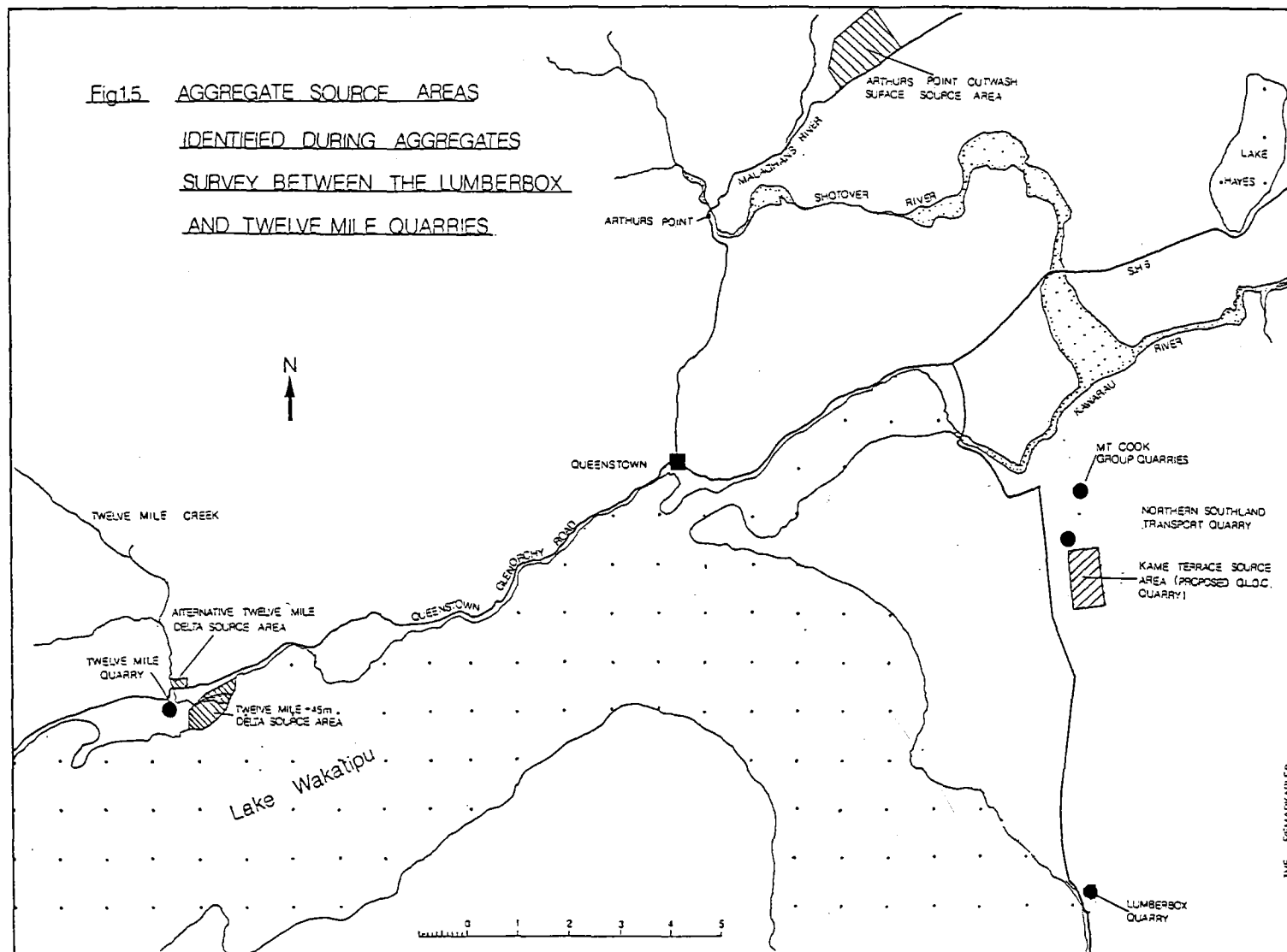
Preliminary field work for the Aggregate Survey was completed in May 1986, and two potential source areas were identified:

(a) Kame terrace deposits along the lower westerly flanks of The Remarkables (fig 1.5); and

(b) Delta deposits associated with the +45m lake level at the Twelve Mile Creek mouth (Fig. 1.5).

On the 17th of June 1986 Council approved further investigations for both potential aggregate source areas. During September 1986 engineering geological mapping at a scale of 1:5000 was carried out at the Twelve Mile +45m Lake Delta deposit. Field work was also carried out during this





month to locate quality aggregate along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads (Fig 1.1).

Site investigations were carried out on kame terrace source area during October 1986. Investigations included engineering geological mapping at scales of 1:10000 and 1:1500, excavation and logging of thirteen test pits, and the collecting of test samples. Test samples included eighteen channel samples collected from the test pits, and a 40 m<sup>3</sup> crushing trial from which six crushed aggregates samples were collected (sampling methods discussed in section 5.2).

During May 1987, field work for the aggregate survey identified the Arthurs Point and alternative Twelve Mile delta source areas (Fig. 1.5). Investigation of these sites included a walkover survey and logging of exposures.

#### (ii) Geotechnical Testing

The following geotechnical testing programme was undertaken to ascertain whether the potential aggregate source areas were capable of producing NRB M/4 roading aggregate:

(a) Grainsize Analysis (NZS 4420 Part 1:1980 Test 9(B) or 9(A));

(b) Proportion of Broken Rock (NRB M/4 1985);

(c) Crushing Resistance (NZS 3111:1980 Section 14);

(d) Sand Equivalent (NZS 4402 Part 1:1980 Test 7);

(e) Weathering Resistance (NZS 3111:1980 Section 15).

Additional geotechnical tests were used to further assess the quality of the aggregates, including:

(a) Los Angeles Abrasion (NZ MOW DES. C 114-69);

(b) Atterberg Limits (NZS 4402 Test 1 & 2 1980);

(c) Clay Index (A.E.L. test method file 12/5/5 No.

83/26);

(d) Lithological Analysis;

(e) X-Ray Diffraction.

The geotechnical testing programme was undertaken at the University of Canterbury, in the Geology and Civil Engineering Departments.

## 1.6 THESIS FORMAT AND TERMINOLOGY

### 1.6.1 Thesis Format

The first two chapters of this thesis study are introductory. In chapter 2 the author introduces the general geology and geomorphology of the Wakatipu Catchment and relates it to aggregate sources. The present roading aggregate resources of the Wakatipu Basin are evaluated and discussed in chapter 3. In chapter 4 the potential aggregate sources identified during the "Aggregate Survey" are described and discussed. In chapter 5 the test results of the geotechnical testing programme are used to assess the quality of the aggregates. In chapter 6 the summary and conclusions of this thesis study are presented.

### 1.6.2 Terminology.

(i) Rock, Soil and Mapping Symbol Terminology.

Field descriptions of rock and soil provided in this thesis study follow those of the New Zealand Geological Survey unpublished Draft Method of Soil and Rock Description for Engineering Use, dated 1985. Symbols used on engineering geology plans and sections are based on those described by the Geological Society Engineering Group Working Party Report (1972).

## CHAPTER TWO

## GEOLOGY AND GEOMORPHOLOGY

## 2.1 INTRODUCTION

Within the Wakatipu Catchment two types of basement rock outcrop, and minor amounts of Tertiary material are also exposed. The surficial deposits of the Wakatipu Catchment are of Late Quaternary age and are typically glacial and post-glacial deposits. It is from these deposits that the roading aggregate of the Wakatipu Basin is derived. In this chapter the author will discuss the general geology of the Wakatipu Catchment, with the purpose of relating the geology and geomorphology of the Wakatipu Catchment to potential aggregate sources.

## 2.2 BASEMENT GEOLOGY

2.2.1 Previous Work

The basement geology of Central Otago has been extensively studied by numerous writers, including: Park (1909), Turner (1935), Hutton and Turner (1936), Grindly (1958), Means (1966), Harper and Landis (1967), Brown (1968), Bishop (1972), Cooper (1972), Kawachi (1974), Coombs et al (1976), Bishop et al (1976), Wood (1978), Turnbull (1979, 1980), Mackinnon (1983) & Craw (1984, 1985). The regional geology of the Wakatipu Basin has been mapped by Wood (1962) at a scale of 1:250000 (Wakatipu Geological sheet).

### 2.2.2 Otago Schists

#### (i) Distribution

Wood (1978) uses the term Otago Schists to describe Haast Schist (Coombs et al 1976) that outcrops in the area lying within the Otago provincial district, and extends northwest to the Haast Valley, incorporating an area of more than 30000 km<sup>2</sup> (Fig. 1.1).

#### (ii) Lithology

The Otago Schists are predominantly quartzofeldspathic, interlayered meta-pelitic and meta-psammities with rare greenschists and meta-cherts (Wood 1978). Coombs et al (1976) proposed that the Otago Schist was the metamorphic equivalent of the amalgamation of two petrographically distinct clastic suites, the Caples and Torless Terrains. However, recent work in the Aspiring area by Craw (1984, 1985) has denoted a third, and perhaps a fourth, association present in the Otago Schists belt, which differs from the Caples and Torless Terrains.

The associations discussed by Craw (1984) are called the "Aspiring Lithological Association" and the "Wanaka Lithological Association". The Aspiring lithological association consists mainly of meta-pelitic schists, subdominant meta-psammitic schist, greenschist, and rare meta-chert and meta-marble. The Wanaka lithological association contains dominant meta-psammatic schist, subdominant meta-pelitic schist and rare meta-chert. The Otago Schist of the Wakatipu Basin lies within the "Aspiring Lithological Association" (Craw 1984).

### (iii) Structure

The macroscopic structural features of the Otago Schist is complex and not clearly understood. Wood (1978) describes the macroscopic structure of the schist as a stack of recumbent nappe like folds flanked by arrays of reclining isoclinal folds.

### (iv) Metamorphic Grade

The Otago Schist can be subdivided into three metamorphic zones (chlorite, biotite and garnet) based on the first appearance of minerals in the parent greywacke (Wood 1978). The exceptionally wide distribution of chlorite zone minerals, in addition to biotite and garnet disequilibrium assemblages, indicates that regional retrogressive metamorphism of a formerly higher ranked central zone has occurred (Wood 1978). Schistosity is well developed and can vary from slightly foliated to strongly foliated (Bishop 1972). Four textural zones (I to IV), reflecting the nature of schistosity were introduced by Turner (1936) and modified by Bishop (1972). The textural zones use the degree of schistosity as a field description for mapping.

### (v) Environment of Deposition

The original age and types of sediment from which the schists are derived is still a point of conjecture. Wood (1978) suggested derivation from quartzofeldspathic greywacke and argillite, with minor bands of submarine volcanics of Permian and Triassic age.

### 2.2.3 Caples Group

#### (i) Distribution

Rocks of the Caples Group outcrop as a belt to the south and west of the Otago Schist (Coombs et al 1976) (fig 1.3). The Caples Group is bounded to the west by the Livingston Fault and the Dun Mountain Ophiolite Belt (Turnbull 1980) (Fig. 1.3). To the east, the Caples Group rock increase in metamorphic grade and become increasingly schistose, and the boundary with the Otago Schist is denoted by Bishop's (1972) Textural Zone II (Turnbull 1980 ).

#### (ii) Lithology

Turnbull (1979) mapped Caples Group rocks in the Thompson Mountains (Fig. 1.3), and recognised five formations, which are continuous with informal and formal units mapped further to the north by Kawachi (1974) and Bishop et al (1976). The five formations are:

- (a) Bold Peak Formation - quartz poor, thick bedded, coarse lithic sandstone;
- (b) Upper Peak Formation - thin bedded, quartz lithic sandstone and siltstone;
- (c) Key Creek Formation - red and green quartz deficient, thick bedded coarse volcanogenic sandstone;
- (d) Mt Campbell Formation - quartose flysch like sandstone and
- (e) Momus Sandstone - quartose flysch like medium sandstone.

The formations are generally conformable, and defined by the use of eight subordinate sedimentary lithofacies. Some lithofacies are restricted to one formation, while others are common to several. Coombs et al (1976) describe the Caples

Group as largely unfossiliferous greywackes and argillites with some spilitic volcanic, limestone and cherty horizons.

### (iii) Structure

The structure of the Caples Group is complex, and multiple deformation phases are recognised. Upward and downward facing tight recumbent folds are developed on a macroscopic scale (Coombs et al 1976).

### (iv) Metamorphic Grade

The metamorphic grade of the Caples Group is described by Turnbull (1980) as pumpellyite-actinolite facies, with lawsonite-albite chlorite facies assemblages occurring in several localities.

### (v) Environment of Deposition

The envisaged environment of deposition for the Caples Group is a submarine fan complex on a lower trench slope (Turnbull 1979). The sediment is predominantly volcanic arc derived, probably from the Brook Street Terrain to the east (Turnbull 1980). Based on limited paleontological data Turnbull (1978) considers the Caples Group to be of late Permian to early Triassic age.

## 2.3 CENOZOIC GEOLOGY

### 2.3.1 Previous Work

Cenozoic geology has been discussed by numerous writers, including Mackay (1897), Park (1906), Hutton (1940), McKellar (1960), Williams (1965), Turnbull et al (1975), Gage (1980) & Bell (1982).



### 2.3.2 Bobs Cove Beds

Within the Wakatipu Basin, a volumetrically minor amount of Tertiary strata is present, preserved as thin unfaulted slivers along the Moonlight Fault zone (fig. 1.3). These Tertiary sediments are mapped as the Bob Cove Beds (Turnbull et al 1976), and represent a sequence of Oligocene marine sediments which include breccia-conglomerates, siltstones and bioclastic limestone.

The Bob Cove Beds were deposited during a marine transgression-regression oscillation which partially extended over a mid Tertiary peneplain (Turnbull et al 1967). The sediments are envisaged by Turnbull et al (1975), to be shallow marine for the base of the sequence, and on a submarine slope leading to a deep marine flysch basin for the remainder of the sequence.

### 2.3.3 Quaternary Glacial Deposits

Glacial deposition within the Wakatipu Catchment is complex, due to the succession of glacial advances that occurred during the Pleistocene. The three youngest glacial advances and their associated deposits can be recognised within the Wakatipu Catchment (Bell 1982). Bell (1982) has made tentative correlations between the glacial events of the Kawarau Valley and the Upper Clutha Valley (Table 2.1). The distribution of ice during the Otiran (last) glaciation and Waimean (penultimate) glaciation is demonstrated in Fig. 2.1.

The Otiran glaciation probably occurred between 30000 and 15000 years ago (Bell 1982), and is responsible for the majority of glacial deposits within the Wakatipu Catchment.

<u>N.Z. Stages</u>		
<u>Interglacial</u> (Aranuian)	<u>Glacial</u>	<u>Glacial Advance</u> -
		youngest Otiran
	Otiran (last glaciation)	late Otiran maximum
		(?) early Otiran advance
Oturian		-
	Waimean (penultimate glaciation)	Waitiri
Terangian		-

Table 2.1 Tentative Late Pleistocene Chronology of the  
Kawarau Valley (after Bell 1980).

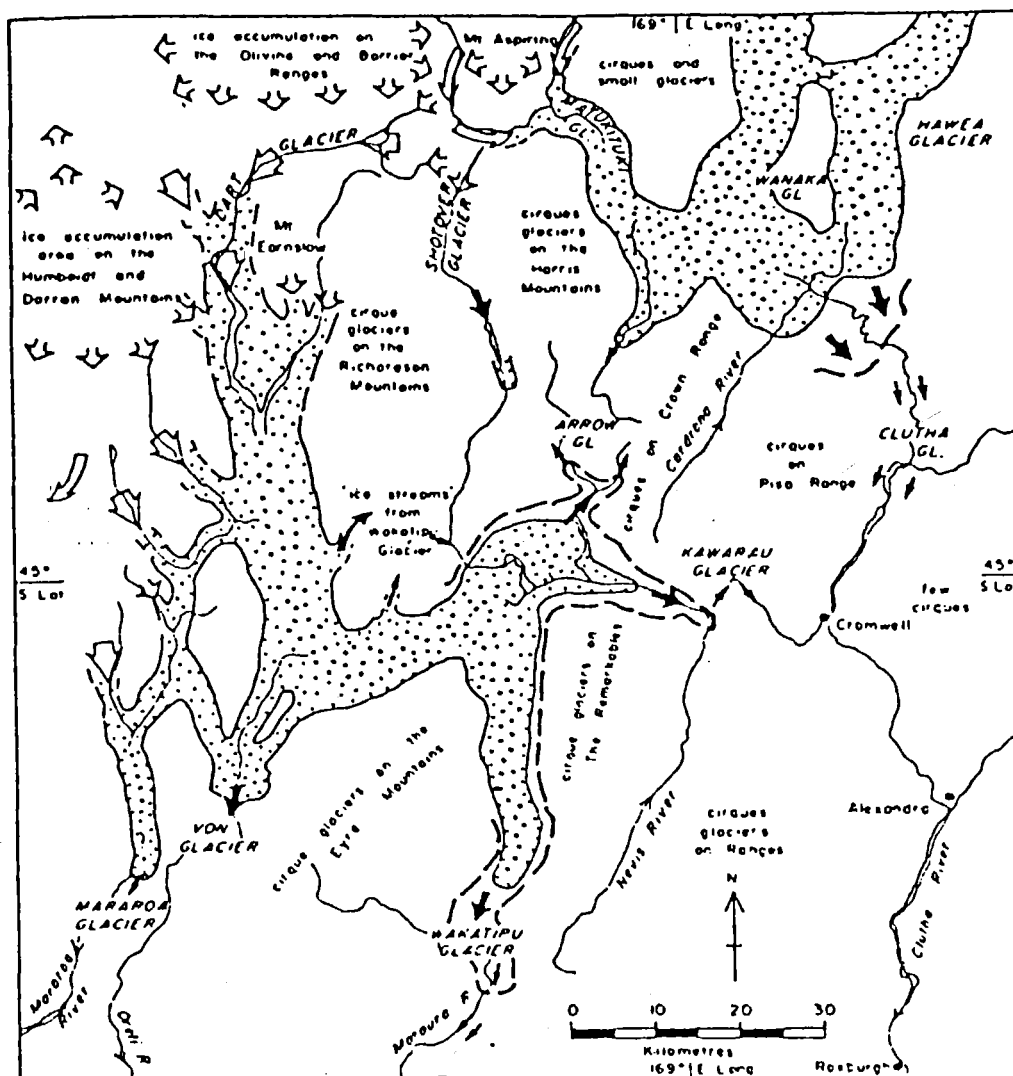


Fig. 2.1 Map showing maximum ice limits for the Last (stippled) and Penultimate (dashed) Glaciations in the Wakatipu and Clutha catchments. Open arrows show the approximate directions of ice movement away from the snow accumulation areas, and the infilled arrows indicate the resultant glacier patterns (after Bell 1982).

As the Wakatipu Glacier advanced it deposited lodgement till directly onto bedrock. Outwash gravels were deposited by streams flowing from terminal moraines. Sediment carried by the glacier was also deposited in streams flowing at the sides of the glacier as kame terraces. During the waning stages of the last glaciation successively lower kame terraces and ablation till were deposited. Alluvial fans were deposited by streams flowing down the steep glacial valley sides.

#### 2.3.4 Quaternary Post-Glacial Deposits

During the Aranuiian post-glacial period an enlarged proto-Lake Wakatipu collected behind the terminal moraine at Kingston. Three post-glacial deposits are related to the elevated lake and its successive lowering. Rivers and creeks upon entering the elevated lake, deposit their sediment load, building out deltas and fan-delta complexes. As the level dropped, lower deltas and fan-delta complexes were formed. Density currents flowing off the deltas and fan-delta complexes deposited sand, silt and clay as lake sediment. Similar sediments are being deposited at the present day lake margin. Stream activity has reworked glacial and post-glacial deposits, with aggregate transported from the catchment above, and deposited alluvial fans on the lower slopes of the valley sides.

### 2.4 GEOMORPHIC EVOLUTION

The geomorphic evolution of the Wakatipu Catchment are discussed by Bell (1982), and is summarised below.

Geomorphic evidence suggests that a topographically mature and tectonically stable landform existed in Central Otago by the Landon (Oligocene) period. This stable landform was then disturbed by the tectonic movements of the Kaikoura Orogeny (which commenced in the early Miocene) and as the rate of uplift increased it seems likely that the Tertiary sediments in the Wakatipu Basin were removed, except for the unfaulted slivers of the Bobs Cove Beds preserved along the Moonlight Fault zone.

Extreme landscape modifications occurred during the successive Pleistocene glaciations. The penultimate and last glaciations in particular had significant effect on the geomorphic development of the Wakatipu Basin, and their well defined imprint can easily be recognised today. Bell (1982) has interpolated the Crown Terrace as being the Penultimate Glaciation valley floor, with more than 350m of ice accumulating at the maximum of the glaciation. The Wakatipu Basin demonstrates "freshly" glaciated topography, ice scorn and mamillated rock surfaces, roche moutonnées (Queenstown and Peninsular Hill), perched glacial erratics, kame terraces and terminal moraine.

The waning of the Otiran Glaciation is expected to have occurred quickly, with a rapid retreat of the ice. An enlarged Lake Wakatipu was then dammed behind the terminal moraine at Kingston (fig. 1.3). Initially the lake level was probably 150m above the present lake level. Creeks flowing into the enlarged lake produced fan-delta complexes and deltas, which can be recognised today at the paleo-lake levels. Lake Wakatipu was progressively lowered, producing successively lower wave cut benches, fan-delta complexes and deltas. Prominent lake levels in the Wakatipu Basin are recog-

nised at +45m and +25m above the present lake level. Less prominent lake levels are also recognised within the Wakatipu Basin at +40m, +30m, +15m and +8m above the present lake level.

The lake lowering was produced by progressive down-cutting of the Kingston outlet. The now abandoned outlet through the Kingston moraine can clearly be recognised today. The present Kawarau outlet of Lake Wakatipu was not in existence, as a bedrock ridge existed south of Morven Hill to the foot of the Remarkables (Fig. 1.1). The Shotover River then became entrenched into bed rock south of Morven Hill, lowering its elevation by the amount necessary to capture the outflow from Lake Wakatipu via Frankton Arm (possibly about 5000 years ago).

## 2.5 LATE QUATERNARY ROADING AGGREGATE SOURCES

### 2.5.1 Potential Sources

Tertiary deposits within the Wakatipu Basin are not suitable for the production of roading aggregate, therefore restricting possible aggregate sources to Late Quaternary deposits. The Late Quaternary deposits within the Wakatipu Basin are predominantly related to the Otiran Glaciation and post-glacial events. Four glacial (Otiran) and three post-glacial deposits are identified as potential aggregate sources. The sources include, Otiran alluvial fans, ablation till, outwash surfaces, kame terraces, deltas, fan-delta complexes and alluvial fans. The relative age, general description and lithology of the gravel fraction, for each of the aggregate sources is provided in Table 2.2. The relative post-

<u>Aggregate Sources</u>	<u>Relative Age</u>	<u>General Description</u>	<u>Lithology of Gravel Fraction</u>	<u>Discussion of Deposit</u>
Alluvial Fan	post-glacial	Sandy fine to coarse Gravel with rare silt	schist, quartz and may contain greywacke	proposed QLDC quarry (section 4.3)
Fan/delta Complex	post-glacial	Sandy fine to coarse Gravel with rare silt	schist, quartz and may contain greywacke	Lumberbox and Two Mile quarries (section 3.2,3.3)
Delta	post-glacial	Sandy fine to coarse Gravel	schist, quartz and may contain greywacke	Arthurs Point, NST, Farry, Twelve Mile, Twenty Five Mile quarries (section 3.5,3.6,3.7, 3.8,3.9)
Kame Terraces	glacial (Otiran)	Sandy fine to coarse Gravel with some silt	schist, quartz and greywacke (10-30%)	Mt Cook quarry, proposed QLDC quarry (section 3.4,4.3)
Outwash	glacial (Otiran)	Gravel with some sand	schist, quartz and greywacke (10-30%)	potential aggregate source area (section 4.6)
Ablation Till	glacial (Otiran)	Sandy fine Gravel with some silt	schist, quartz and greywacke (20-40%)	Mapped fig.4.2 (section 4.2)
Otiran Alluvial Fan	glacial (Otiran)	Gravel with some sand and rare silt and cobbles	schist and quartz	Mapped fig.4.2 (section 4.2)

NB: QLDC: Queenstown Lakes District Council.  
NST: Northern Southern Transport.

Table 2.2 Data summary of aggregate sources recognised in the Wakatipu Basin.

tions (except for outwash surfaces) of the aggregate sources are demonstrated in Fig. 2.2).

Ablation till has been used as a low grade roading aggregate on the Fernhill subdivision (pers comm D Bell). However, particle size distribution carried out by Bell (1982 b) demonstrates that the ablation till contains between 11-27% silt, with the majority of gravel being fine grained. The particle size distribution suggest that ablation till does not contain suitable coarse grained ( $> 20\text{mm}$ ) aggregate for the production of basecourse. Therefore, it is noted that ablation till is a possible source of low grade roading aggregate, but for the purpose of this thesis study (ie. location of aggregate capable of producing quality base-course) ablation till will not be considered as a potential aggregate source.

#### 2.5.2 Otiran Alluvial Fans

##### (i) Lithology and Texture.

The alluvial material consists of a schist Gravel with some sand, deposited in lenses which dip down slope at approximately  $15-25^{\circ}$ . Typically exposures indicate that the alluvial material is greater than 10m in thickness.

##### (ii) Depositional Environment.

The fans are presumed to have been formed by creeks flowing down mountain slopes, during the Otiran glacial time period. The creeks transported locally derived schist aggregate from the above catchments, depositing the material adjacent to the glacier. Exposures on the lower western slopes of The Remarkables show the Otiran alluvial fan overlain by kame terrace material, inferring that the alluvium was deposited



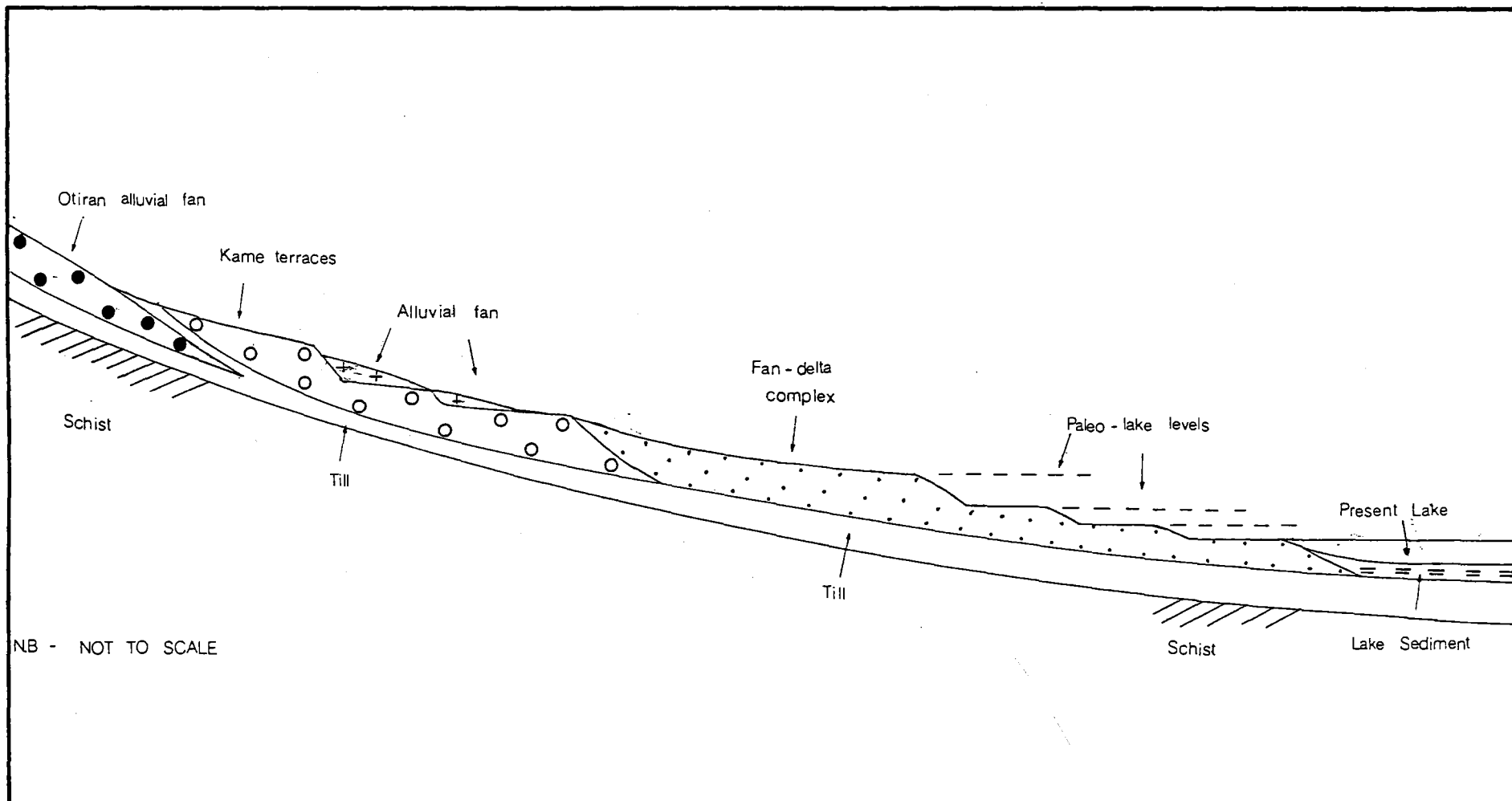


Fig. 2.2 Relative positions of aggregate sources recognised in the Wakatipu Basin (idealised).

at an earlier date, possibly during an earlier advance of the Otiran glaciation. However, there is a possibility that the alluvial fans were deposited during the Oturian inter glacial period.

### (iii) Distribution

Otiran alluvial fans have been investigated by the author on the lower westerly slopes of The Remarkables (Fig 1.1), Bell (1976), Lewondowski (1976) and Browne (1987) have also identified Otiran alluvial fans at this location.

### (iv) Inferred Quality

Crushing resistance values of roading aggregate produced from Otiran alluvial fan is envisaged to be of sub-M/4 standard, unless greywacke is present. High sand equivalent values are not expected, as the aggregate has been partially "washed" during deposition.

## 2.5.3 Kame Terraces

### (i) Lithology and Texture.

The kame terrace material is massive to coarsely bedded, consisting of mixed schist and greywacke (10-30%) graevl and finer debris (Fig. 2.4). The material varies from sandy gravel to gravelly silt, and contains occasional lenses of silt and till inclusions. The material is variable laterally, with abrupt changes in grain size. Kame terrace material demonstrates a variable thickness, the upper kame terraces have a measured thickness of 2m and the lower terraces have an inferred thickness from exposures of at least 10m.

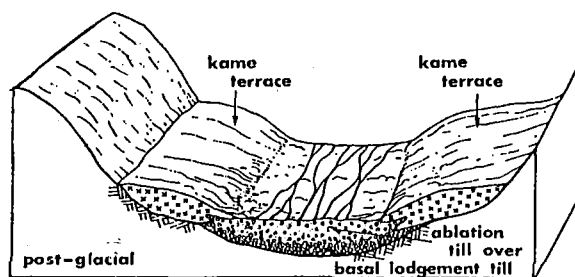
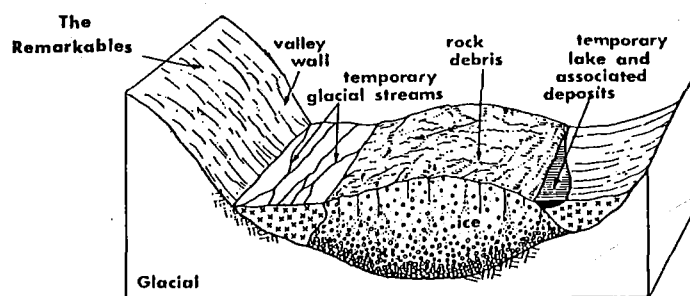


Fig. 2.3 Kame terraces development (idealised) (modified after Fookes et al. 1978).

### (ii) Depositional Environment

Kame terraces are deposited by streams flowing at the side of the glacier in the depression between the ice and the valley wall (Fig 2.3). Morainic material is also thought to slump off the glacier or the valley wall and be deposited as inclusions of till in the kame terrace aggregate. Due to the different depositional environments the kame terrace material is variable laterally, with abrupt changes from coarse to fine grained material, and often contains lenses of till. Occasional fine grained lenses present within the kame terrace material, are expected to have been deposited in small lakes impounded between the ice margin and the ice free slope (Fig. 2.3). As the glacier waned, successively lower terraces were deposited.

### (iii) Distribution

Kame terraces have been investigated by the author on the lower westerly slopes of The Remarkables (Fig. 2.5) Bell (1976), Lewandowski (1976) and Browne (1987), have also identified kame terraces in this location.

### (iv) Inferred Quality

Kame terrace roading aggregate is envisaged to have crushing resistance values of M/4 standard, because of the greywacke content. However, the glacial origin may produce sub-M/4 sand equivalent values.

## 2.5.4 Outwash Gravel

### (i) Distribution.

The outwash deposit investigated by the author has been informally named by Bell (1982) as the Arthurs Point outwash



Fig. 2.4 Kame terrace aggregate exposed at Mt Cook Group Quarry on the lower westerly slopes of The Remarkables, (camera case 15cm long).



Fig. 2.5 Kame terraces on the lower western slopes of The Remarkables.

surface, and is located at the base of Coronet Peak (Fig. 1.5).

#### (ii) Lithology and Texture

The outwash deposit is massive, and consist of mixed schist and greywacke, fine to coarse Gravel. Exposures of the outwash surface suggest a thickness of at least 4m.

#### (iii) Depositional Environment

During the waning stages of the Otiran glaciation the receding glacier is envisaged to have deposited the Arthurs Point recessional moraine (informally named by Bell 1982). Streams flowing from the moraine are inferred to have deposited the Arthurs Point outwash in the topographical depression at the base of Coronet Peak (Fig. 2.6).

#### (iv) Inferred Quality

The greywacke content of the outwash aggregate is suggested to produce M/4 quality crushing resistance values. Outwash surfaces are typically deposited by fast flowing streams, and this is envisaged to have "washed" the aggregate producing M/4 quality sand equivalent values.

### 2.5.5 Fan-Delta Complexes

#### (i) Lithology and Texture

The fan-delta complexes generally consist of bedded silt, sand, and gravel mixtures, with a reduction in grain size noticeable within the fan-delta complex from proximal to distal location (Fig. 2.7). The fan section of a fan-delta complex is well to poorly graded, massive to laminated material, which slopes towards the lake at 5-10°. The subaqueous



Fig. 2.6 Arthurs Point recessional moraine and outwash surface, moraine in central view (A) and outwash surface in right field of view (B).



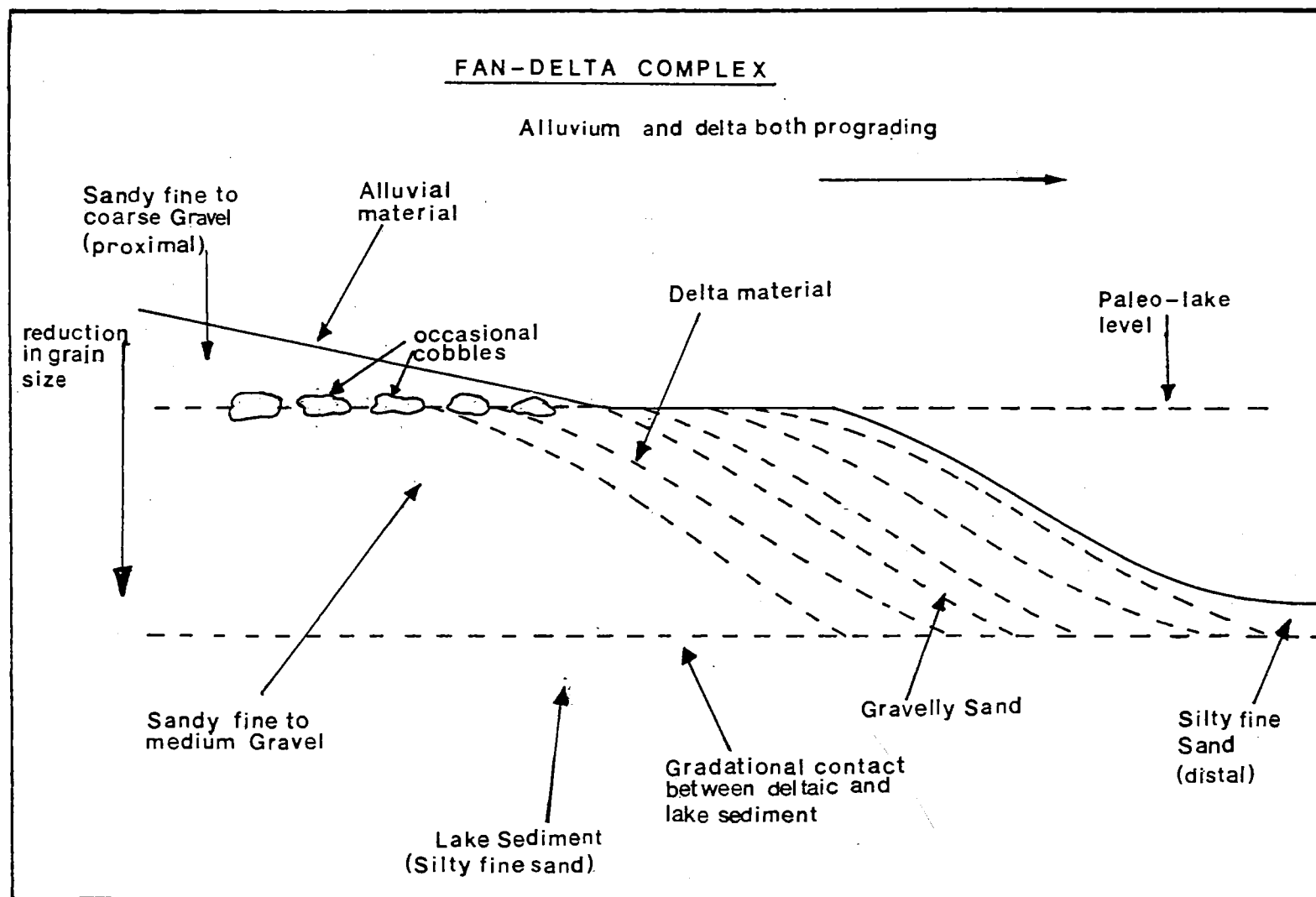


Fig. 2.7 Simplified schematic cross section of a fan-delta complex.

deltaic material is poorly graded, occasionally laminated with gravelly sand (fines rich) and sandy gravel (fines poor) lenses which are horizontal, or dip towards the lake at 15-30°. The deltaic material often contains deltaic sedimentary structures such as channels, climbing ripples, cross bedding and foresets.

The thickness of the fan-delta complexes varies between complexes. A small complex may be <2m in thickness while a larger complex may be >30m in thickness. Exposures available demonstrate that fan-delta complexes become increasingly fine grained at the distal location of the complex and grade into lake sediment.

#### (ii) Depositional Environment

The deposits are called fan-delta complexes because they demonstrate both subaqueous and subaerial depositional environments. At the paleo-lake levels, the fan-delta complexes demonstrate a distinct change in depositional environment from subaerial to subaqueous (Fig. 2.7). The reduction in grain size is related to the proximal and distal depositional environments of the complex. At a distal environment, the fan-delta complexes deposit silt, sand and fine gravel mixtures. At a proximal environment, the fan-delta complexes deposit sandy gravel mixtures.

It is envisaged that the fan-delta complexes were deposited since the retreat of the Otiran glaciation by creeks flowing down the steep glaciated valley walls. Upon reaching the paleo-lake level, the creeks deposit their sediment load and form the "fan" section of the fan-delta complex. The sediment is then transported to the lake and deposited in a deltaic environment. Both sections of the complex prograde

out into the lake. As the enlarged lake was lowered, successively lower fan-delta complexes were deposited. A simplified schematic cross section of a fan-delta complex is provided in fig. 2.7.

#### (iii) Distribution

Bell (1982,1985) has described several fan-delta complexes within the Wakatipu Basin and comments that fan-delta complexes are present at elevations of up to 150m above Lake Wakatipu's present elevation. Browne (1987) has also mapped a similar unit to the fan-delta complex unit at the base of the Remarkables Ski Field road. Browne has called this unit alluvial fan, but comments that it contains deltaic material. Several prominent Lake levels, +45m and +25m, and their associated fan-delta complexes can be recognised around the periphery of Lake Wakatipu (Fig. 2.8). The Lumberbox quarry, which is a major producer of quality roading aggregate within the Wakatipu Basin, is produced from fan-delta complex aggregate (Fig. 2.8) (see section 3.2).

#### (iv) Inferred Quality

Fan-delta complexes that occur on the north west side of Lake Wakatipu (ie. within catchments that receive Caples Group aggregate) or which are derived from glacial material, contain a percentage of greywacke and are inferred to produce M/4 crushing resistance values. The deltaic section of the fan-delta complex has been washed and is postulated to produce M/4 sand equivalent values.



Fig. 2.8 Fan-delta complex located on the lower western slopes of The Remarkables, note Lumberbox quarry in central view.

### 2.5.6 Deltas

#### (i) Lithology and Texture

The delta deposits are bedded and consist of sandy gravel mixtures, with a general reduction in grain size noticeable from proximal to distal location within the fan-delta complex. The deltas contain deltaic sedimentary structures such as channels, climbing ripples, cross bedding and foresets (Fig. 2.9). Exposures suggest that some of the larger delta sequences may possibly be 45m in thickness, however smaller deltas may be less than 10m in thickness. The deltas become increasingly finer grained in the distal location the of fan-delta complex and grade into lake sediment.

#### (ii) Depositional Environment

The reduction in grain size within the fan-delta complex is related to the proximal and distal environments of the deltaic deposit. At a distal environment deltas deposit gravelly sand mixtures. At a proximal environment deltas deposit sandy gravel mixtures. Deltas are presumed to have been formed since the retreat of the Otiran glaciation when a river or creek entered the enlarged lake and deposited its sediment load, building out a delta. As the enlarged Lake Wakatipu was lowered, successively lower deltas were deposited. In some localities (e.g. Twelve Mile Creek) several deltas representing the more prominent lake levels of +45m and +25m can be recognised (Fig. 2.10). Deltas are differentiated from fan-delta complexes, as deltas do not contain subaerial depositional structures or an "fan" section. Deltas are inferred to have been deposited in a higher energy environment to the fan-delta complex, therefore do not contain an alluvial fan section.



Fig. 2.9 Deltaic aggregate exposed at the Northern Southland Transport quarry, note the poorly graded nature and lack of coarse gravel fraction (camera case 15cm long).





Fig. 2.10 Twelve Mile  $\pm 45\text{m}$  delta, note deltaic material deposited at lower lake levels.

(iii) Distribution.

Deltas occur commonly throughout the Wakatipu Basin, around the periphery of Lake Wakatipu, and they are associated with the larger rivers and creeks of the Basin e.g. Shotover River, Twelve Mile Creek, Twenty Five Mile Creek, Greenstone and Von Rivers.

(iv) Inferred Quality

Deltas that occur on the north west side of Lake Wakatipu (ie. within catchments that receive Caples Group material) or are derived from glacial deposits may contain a percentage of greywacke and are envisaged to produce M/4 crushing resistance values. The deltaic environment is envisaged to have washed the aggregate, producing sand equivalent values of M/4 quality.

#### 2.5.7 Aranuian Alluvium Fans

(i) Lithology and Texture

Fan alluvium deposits are bedded, and consist of sandy gravel, which dip down slope at approximately  $5-10^0$  (Fig. 2.11). Typical fans are inferred to have a thickness of greater than 3m.

(ii) Depositional Environment.

The Aranian fan alluvium is inferred to have been deposited by stream activity since the retreat of the Otiran glaciation. Streams flowing down valley sides have transported material from the above catchments and reworked the glacial and/or post-glacial material to produce the alluvial fans. The alluvial fans can be differentiated from the fan-delta





Fig. 2.11 Alluvial fan located on the lower western slopes of The Remarkables.

complexes, as the Aranian alluvial fans are not associated with any paleo-lake levels.

(iii) Inferred Quality.

Fans that have reworked glacial deposits are suggested to contain greywacke, therefore may produce M/4 crushing resistance values. The envisaged sand equivalent values of the fan alluvium is low because the fan alluvium has only been partially "washed" during deposition.

## 2.6 SYNTHESIS.

Within the Wakatipu Catchment two types of basement rock outcrop, the Otago Schist and Caples Group. Rocks of the Caples Group outcrop on the north west side of Lake Wakatipu and can generally be described as dominantly greywackes and argillites of late Permian to early Triassic age. The two basement types are of different metamorphic grades, the Caples Group rocks grading into the higher metamorphic equivalent of Otago Schist. Otago Schist can generally be described as quartzofeldspathic schists of the Chlorite metamorphic zone, and parent rocks are of Permian and Triassic age.

An extensively weathered erosion surface had developed on basement by the Mid-Tertiary times. This was followed by the tectonic movements of the Kaikoura Orogeny, which developed the "basin and range" topography of Central Otago. Tertiary sediments within the Wakatipu Basin are poorly represented and are only preserved as infaulted slivers along the Moonlight Fault zone.

Successive glacial advances were active within the Wakatipu Catchment during the Pleistocene, the three youngest of these can be recognised. The glaciations extensively modified the landscape, with the present geomorphology in particular reflecting the last glaciation. As the ice melted, proto-Lake Wakatipu became dammed behind terminal moraine at Kingston. In early post-glacial times the lake level was approximately 150m higher than the present lake, level and was progressively lowered as the outlets were downcut. Post-glacial deltas and fan-delta complexes deposited at prominent proto-Lake levels encircle Lake Wakatipu.

Late Quarternary deposits provide the aggregate sources of the Wakatipu Basin. Six potential aggregate sources are identified, three glacial (Otiran) and three post-glacial. The potential aggregate sources include, Otiran alluvial fans, outwash surfaces, kame terraces, deltas, fan-delta complexes and Aranian alluvial fans.

Potential aggregate sources which have been "washed", during deposition (eg. fan-delta complexes and deltas) are expected to be capable of producing M/4 sand equivalent values, and aggregate sources which contain more than 10% greywacke are predicted to produce M/4 crushing resistance values.

## CHAPTER THREE

### EXISTING ROADING AGGREGATE RESOURCES

#### 3.1 INTRODUCTION

An evaluation programme of the existing aggregate resources within the Wakatipu Basin has been carried out. The purpose of the evaluation programme is to provide a general appraisal of existing aggregate resources, and to identify any existing aggregate resource capable of producing roading aggregate of NRB M/4 quality or suitable for use as a base-course.

In this Chapter the author assesses existing roading aggregate within the Wakatipu Basin, the assessment is based on a description of the quarry or gravel licence, an engineering geological description of the aggregate, and interpretation and discussion of previous NRB M/4 test results for the aggregates.

The testing or retesting of existing roading aggregate resources was not considered, due to the cost of transporting large amounts of test samples from Queenstown to Christchurch, and the time it would require to carry out a NRB testing programme for each resource. The quality of the existing aggregate resources is therefore based on previous test results. Where no tests have been carried out or where results were unavailable, quality estimation is based on comparison with aggregates of similar engineering geological

description and depositional environment of known quality. Therefore the estimations of aggregate quality are tentative, and are provided with the desire only to indicate aggregate and roading aggregate quality. A data summary of roading aggregate quarries is provided in Table 3.1.

### 3.2 LUMBERBOX QUARRY

#### 3.2.1 Quarry Description

The Lumberbox Quarry is located 11km south of Frankton, adjacent to and on the uphill side of State Highway Six, and on the true right bank of the Lumberbox Creek (Fig. 3.1). The Lumberbox quarry is owned by the Ministry of Works and Development.

Production of aggregate at the quarry involves a screening and crushing operation. Firstly the aggregate is screened with the -19mm fraction removed, then the remaining aggregate is crushed (pers comm R. Duff, County Engineer). During the scalping operation approximately 50 % of the original mass is removed and stockpiled. Scalpings are occasionally used as low grade roading aggregate.

#### 3.2.2 Engineering Geology

##### (i) Engineering Geology Description

The Lumberbox quarry is coarsely bedded and consists of sandy gravel mixtures. The deposit demonstrates an upwards coarsening of grain size. The clasts are rounded to subangular with a minor amount (10%) of clasts demonstrating an elongate or discoidal shape (Table 3.1).

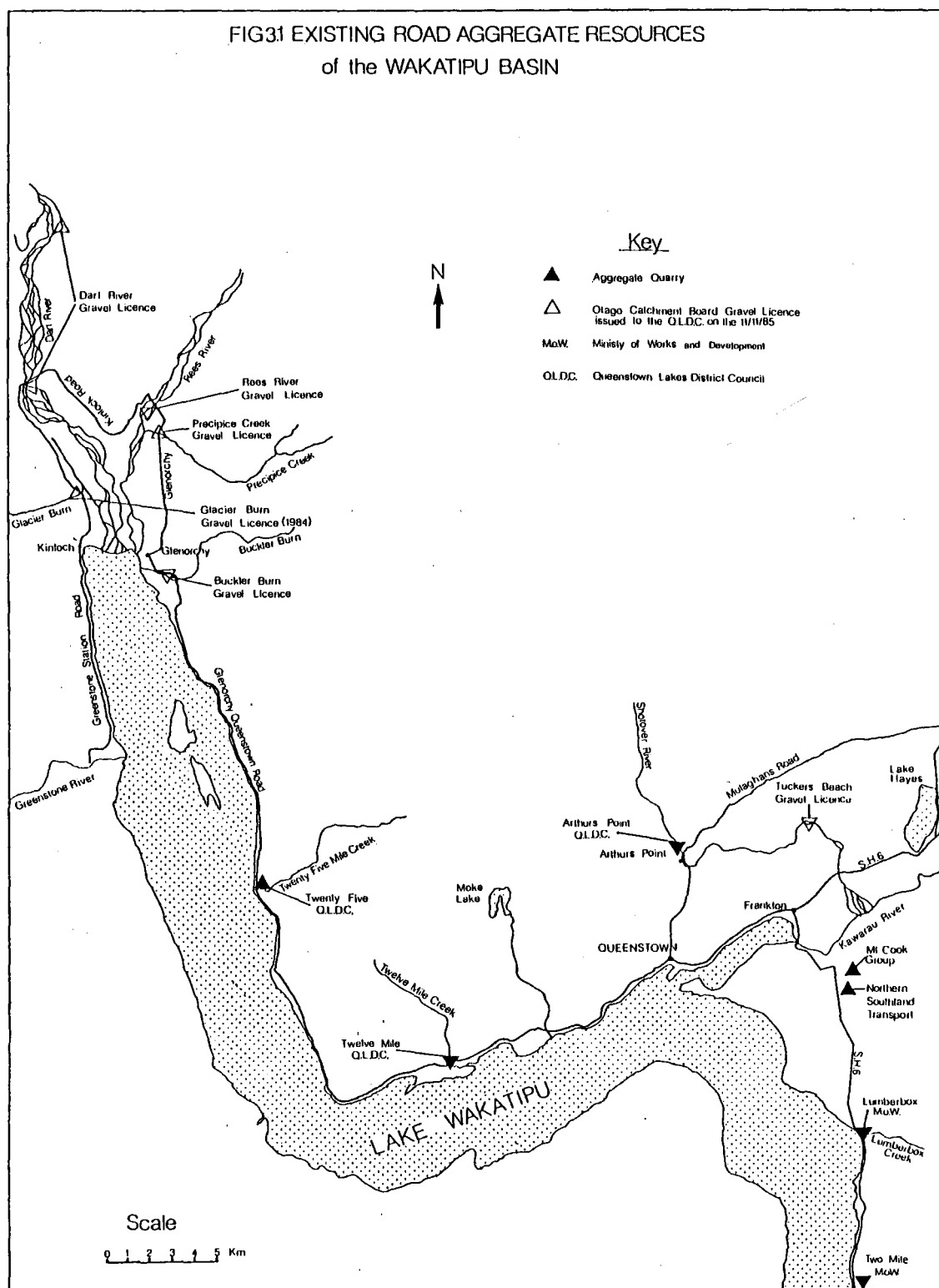
A field description of the aggregate is as follows;

Aggregate Quarry	Depositional Environment	General Description	Lithology of Gravel Fraction	Particle Shape
Lumberbox	fan delta complex	Sandy fine to course Gravel with some silt	TZ II, III, IV, quartz and greywacke (30-40%)	suba-subr 10% discoidal
Two Mile	fan delta complex	Sandy fine to course Gravel	TZ II, III, IV, quartz and greywacke (20-30%)	suba-subr 10% discoidal
Mt Cook Group	kame terraces	Sandy fine to course Gravel with some silt	TZ II, III, IV, quartz and greywacke (20-30%)	suba-subr 10% discoidal
Northern South-land Transport	delta	Sandy fine to medium Gravel	TZ II, III, IV, quartz and greywacke ( 5%)	suba-subr 10-20% discoidal
Ferry	delta	Sandy fine to course Gravel	TZ II, III, IV, quartz and greywacke ( 5%)	suba-subr 20% discoidal
Twelve Mile	delta	Sandy fine to course Gravel	TZ II, III, IV, quartz and greywacke ( 5%)	suba-subr 20% discoidal
Twenty Five Mile	delta	Sandy fine to course Gravel	TZ II, III, IV, quartz	suba-subr 20% discoidal
Arthurs Point	delta	Sandy fine to course Gravel	TZ III and IV	suba-subr 20% discoidal

NB:suba: subangular  
subr: subrounded

Table 3.1 Data summary of roading aggregate quarries within the Wakatipu Basin.

FIG31 EXISTING ROAD AGGREGATE RESOURCES  
of the WAKATIPU BASIN



Light grey, unweathered, massive to crudely bedded, SANDY fine to coarse GRAVEL with some silt and rare boulders and cobbles (GW/GM).

compact-loose; moist; well to poorly graded; bedding, gently inclined, thick; gravel subangular to rounded, TZ II, III and IV schist, quartz and greywacke (30-40%); sand, fine to coarse; silt non-plastic; with occasional open textured gravel lenses and crossbedded sand lenses.

### (ii) Depositional Environment

The Lumberbox material is thought to have been deposited as a fan-delta complex into an enlarged Lake Wakatipu since the retreat of the last glaciation (Fig. 2.8). The deposit demonstrates structures such as upward coarsening, crude laminations gently inclined down slope, graded bedding, cross bedding and open textured gravel lenses, which suggests a combination of alluvial fan and deltaic environments. Fan-delta complexes deposited at lower lake levels are present below the Lumberbox quarry.

The high greywacke content of the Lumberbox material was partially or wholly derived from glacial material, probably kame terrace or till deposits. Some geomorphic expression of kame terraces is visible upslope of the quarry.

### 3.2.3 Geotechnical Test Results

M/4 test results completed on crushed aggregate samples are presented in Table 3.2. Roding aggregate produced at the Lumberbox quarry does not meet the NRB M/4 standard, but it does produce the highest quality aggregate within the Wakatipu Basin (Wathey 1984).



(i) Sand Equivalent Values.

The roading aggregate fails to comply with the NRB M/4 specification as the aggregate has sand equivalent values which range from 18 to 35. Low sand equivalent values of the aggregate is attributable to the fluvio-glacial origin of the deposit. Non-plastic glacial silts and clays adhere strongly to the clasts, and are present in lenses within the deposit. Scalping removes the silt and clay within the aggregate, but the fines which adhere to the clasts survive the scalping process and produce low sand equivalent values.

The original quarry was much "cleaner", with sand equivalent values ranging from 49 to 57, but as the quarry has developed the aggregate became "dirtier", with sand equivalent values ranging from 16 to 35 (Wathey 1984). The decrease in sand equivalent values is thought to be related to the fan-delta complex structure. The original development of the Lumberbox exposes the "deltaic" section of a fan-delta complex. The "deltaic" section of a fan-delta complex is "washed" during deposition, and will therefore produce high sand equivalent values. As the Lumberbox quarry was developed it worked upslope into the "fan" section of the fan-delta complex. The "fan" section of a fan-delta complex is only partially "washed" during deposition and contains sufficient silt to produce low sand equivalent values.

(ii) Crushing Resistance Values.

The crushing resistance values of 180kN to 190kN obtained from the Lumberbox quarry are the highest recorded within the Wakatipu Basin. The high crushing resistance values are related to the greywacke content (30-40 %) of the Lumberbox aggregate.

(iii) Aggregate Washing.

Although problems involving low sand equivalent values have been encountered when using the Lumberbox aggregate, it is the only major source of aggregate that consistently meets the NRB M/4 crushing resistance specification in the Wakatipu Basin. Therefore, the NRB decided to wash the aggregate to meet the NRB M/4 sand equivalent specification (Wathey 1984). Washing was completed by pumping water from the Lumberbox Creek onto the screens. Before washing, the aggregate produced sand equivalent values of 16 to 25, and after a single washing the sand equivalent values had improved slightly to 31. The method of washing the aggregate proved to be largely ineffective, and the washings were difficult to dispose of without polluting Lake Wakatipu. Wathey (1984) suggests that the cost of installing adequate washing facilities at the Lumberbox would be prohibitive due to the type of plant and construction required to effectively dispose of the washings.

A second attempt at washing the Lumberbox aggregate was tried during shape correction work on a section of State Highway Six near the Shotover River (Wathey 1984). Screened aggregate from the Lumberbox was transported to the Shotover River where the aggregate was washed by a concrete aggregate washing plant. The aggregate was washed and then crushed but it was found that two washings were required to produce aggregate that complied with NRB M/4 specifications. A single washing produced a sand equivalent of 31, two washings produced a sand equivalent of 59 to 69. Wathey (1984) comments that the cost of producing the roading aggregate was prohibitive and the method was not used again.

#### (iv) General Aggregate Qualities.

Wathey (1984) comments that the Lumberbox roading aggregate has excellent wearing qualities and when crushed to NRB M/4 grading produces a dense, tightly bound aggregate which is relatively easy to lay and construct as a base-course. The glacial fines which adhere to the aggregate clasts do not seem to be affected by frosts or excess moisture, but do prevent bitumen adherence to the aggregate. The poor adherence of bitumen to the aggregate has been combated by allowing the laid surface to weather before the seal coat is applied. The glacial fines have not affected the performance of the roading aggregate. Wathey (1984) suggests that the glacial fines may even have a beneficial rather than a detrimental effect, as the fines act as a cementing agent. However, no tests have been carried out to prove this hypothesis.

#### (v) Wakatipu Test Sections.

Three test sections were constructed by the Ministry of Works and Development in early 1985 on State Highway Six north of the Lumberbox quarry. The test sections are part of the Research Project BC53 and were constructed to monitor the production, placement and performance of roading aggregate produced at the Lumberbox quarry. Two test sections were constructed from roading aggregate produced at the Lumberbox quarry. The third test section is used as control section, and is constructed from NRB M/4 roading aggregate produced at Lowburn (Table 3.3). A summary of geotechnical results for the test section is provided in Table 3.3. Bartley et al (1986) comments that all the aggregates suffered some degradation during compaction, however the fines were

Existing Roading Aggregate Resources	Sand Equivalent	Crushing Resistance kN	Los Angeles Abrasion %	Weathering Resistance	Reference
Lumberbox Quarry	118 - 35	180 - 190	22 - 29	BA	Bartley (1980)
Two Mile Quarry	48	180	-	-	pers. comm MWD.
Mt Cook Group Quarry ±	57	165, 180	-	-	Bell (1980)
Northern Southland Transport Quarry ±	70	71	-	-	Bell (1980)
Ferry Quarry	-	140	-	-	Lindsay (1987)
Twelve Mile Quarry	40 - 60	105 - 130	41	-	Wathey (1984) and pers. comm MWD.
Tuckers Beach ±	56 - 89	95, 100	45 - 60	-	Wathey (1984) and pers. comm MWD.
Dart River Bridge ±	85, 97	-	34 - 38	-	Wathey (1984)

NB: ±: tests carried out on uncrushed aggregate.  
 ±: Queenstown Lakes District Council gravel licence.

Table 3.2 Geotechnical test results for existing roading aggregate resources from the Wakatipu Basin.

Geotechnical Tests	All-in Crushed (Lumberbox)	Scalped/crushed (Lumberbox)	NRB M/4 (Lowburn)
Plasticity Index	4%	NP	NP
Clay Index	1.9	1.5	1.7
Sand Equivalent	18	22	55
Crushing Resistance	190kN	ND	ND
Weathering Resistance	BA	ND	ND

NP = non plastic

ND = not determined

Table 3.3 Summary of geotechnical results for the Wakatipu Test Sections (after Bartley et al. 1986).

non-plastic and may have resulted in a denser more stable pavement than would otherwise be the case. Both of the Lumberbox test sections have sand equivalent values of 18 and 22, well below the M/4 requirement. However, and may the current loading of the test sections is  $5 \times 10^4$  EDA per year and that all test section were reported to be in excellent condition (Bartley 1987).

### 3.3 TWO MILE QUARRY

#### 3.3.1 Quarry Description

The Two Mile quarry is located adjacent to State Highway Six, 16km south of Frankton on the uphill side of the road and on the true left bank of Two Mile Creek. The quarry is owned by the Ministry of Works and Development.

Wathey (1984) comments that the Two Mile quarry could provide sufficient material for shape correction and maintenance work in the Two Mile district for approximately three years.

#### 3.3.2 Engineering Geology

##### (i) Engineering Geological Description

The Two Mile deposit is massive to bedded and consist of sandy gravel mixtures. The deposit is laterally consistent with no recognisable gross grain size variation. Particle shape is rounded to subangular with approximately 10% demonstrating a discoidal and elongate shape (Table 3.1). A field description of the aggregate is as follows;

Light grey, unweathered, massive to crudely bedded, SANDY fine to coarse GRAVEL with rare cobbles and silt

(GW/GP).

compact-loose; dry; well to poorly graded; bedding sub-horizontal to moderately inclined, thick; gravel subangular to subrounded, TZ II, III and IV schist, quartz and greywacke (20-30%); sand, fine to coarse; silt non-plastic; with occasional open textured gravel lenses.

#### (ii) Depositional Environment

Two Mile quarry exposes a fan-delta complex which have been deposited since the retreat of the last glaciation when Lake Wakatipu was approximately 45m above the present level. Deltaic and alluvial sedimentary structures can be recognized within the deposit and the presence of greywacke indicates reworking of greywacke rich glacial material, presumably lateral moraine and kame terrace material.

#### 3.3.3 Geotechnical Test Results

Limited test results (Table. 3.2) indicate that the Two Mile roading aggregate is of M/4 quality. However additional tests would be required to establish whether the aggregate complies with the M/4 sand equivalent requirement, as similar glacial derived material (e.g. Lumberbox) has demonstrated low sand equivalent values. The greywacke content of the aggregate produces high crushing resistance values values of 180kN, similar to the Lumberbox quarry.

### 3.4 MT COOK GROUP QUARRIES.

#### 3.4.1 Quarry Description.

The quarries are located adjacent to the Remarkables

Ski Field road approximately two and three km from the base of the road (Fig. 3.1). The quarries are owned by the Mt Cook group. Aggregate from the quarry is screened and crushed, and used for roading aggregate on the Remarkables Ski Field road.

### 3.4.2 Engineering Geology.

#### (i) Engineering Geological Description

The quarries are massive to co<sup>a</sup>rsely bedded, and consist of silt, sand and gravel mixtures (Fig. 2.4). The deposit is laterally variable, ranging from coarse grained gravel to silty sand. Particle shape is rounded to subangular with approximately 10% demonstrating a discoidal and elongate shape (Table 3.1). A field description of the quarry aggregate is as follows;

Light greenish grey, unweathered, massive to bedded, SANDY fine to coarse GRAVEL with some silt and rare cobbles (GW/GM).

compact-loose; dry; well to poorly graded; bedding sub-horizontal, thick; gravel subangular to rounded, TZ II, III and IV schist, quartz and greywacke (20-30%); sand, fine to coarse; silt non-plastic; with occasional sand/silt lenses.

#### (ii) Depositional Environment

The two Mt Cook Group quarries expose kame terraces deposited on the lower western slopes of The Remarkables during the later stages of the Otiran glaciation. The quarries demonstrate the typical coarse grained and variable nature of the kame terrace material (discussed in section 2.5.3).



### 3.4.3 Geotechnical Test Results

During preliminary investigations of roading aggregate sources for the Remarkables Ski Field road, four samples were collected from the proposed road alignment (Bell 1980). Two of the samples were collected from kame terrace material similar to the quarries presently used by the Mt Cook Group. Grading, sand equivalent and crushing resistance tests were carried out (Table 3.2) by Bell (1980) on the uncrushed "as received" samples.

Tests as specified by the M/4 specification are carried out on crushed aggregate. Therefore, only a general comparison can be made when comparing the uncrushed quality of the kame terrace aggregate with roading aggregate (crushed) from other quarries within the Wakatipu Basin.

Two sand equivalent values from the kame terrace material suggest that the aggregate is cleaner than similar glacial derived material such as the Lumberbox. However additional testing would be required to establish if the kame terrace material consistently has sand equivalent values of greater than 40. The two crushing resistance values meet the M/4 standard and are similar to crushing resistance values of material with similar field description and greywacke content e.g. Lumberbox.

## 3.5 NORTHERN SOUTHLAND TRANSPORT

### 3.5.1 Quarry Description

Northern Southland Transport quarry is situated 200 m off State Highway Six on the uphill side of the road (Fig. 3.1). The quarry is owned by Northern Southland Transport.

Aggregate from the quarry is not screened or crushed and is used excavated from the face as low quality subbase material (Bell 1980).

### 3.5.2 Engineering Geology.

#### (i) Engineering Geological Description

Northern Southland Transport quarry exposes bedded, sandy gravel mixtures (Fig. 2.9). The deposit is laterally consistent with no gross grain size variation identified. Particle shape is subrounded to subangular with approximately, 10-20 % demonstrating a discoidal and elongate shape (Table 3.1). A field description of the aggregate is as follows;

Light grey, unweathered, bedded, SANDY fine to medium GRAVEL (GW/GP).

compact-loose; dry; well to poorly graded; bedding sub-horizontal to moderately inclined, thin to thick; gravel sub-angular to subrounded, TZ II, III and IV schist, quartz and greywacke (5%); sand, fine to coarse; with occasional gravel lenses and sand lenses.

#### (ii) Depositional Environment

The quarry exposes a delta, deposited after the retreat of the last glaciation. The presence of greywacke indicates the reworking of glacial material, presumably the kame terrace material which is exposed immediately above the delta sediments. From field descriptions a difference in greywacke content between the kame terrace (20-30 %) and deltaic (5 %) material is evident. A probable reason for this is that the creek which deposited the delta originated in the catchment above the terraces and transported schist material down with

it, therefore effectively diluting the greywacke content of the reworked kame terrace material. Several deltaic deposits occur at this and lower levels at the base of The Remarkables.

### 3.5.3 Geotechnical Test Results.

Limited test results (Table 3.2) were completed on uncrushed samples from the quarry. The aggregate is of sub M/4 standard and fails to meet the required crushing resistance value. The lack of strength demonstrated by the crushing resistance value is attributable to the predominance of schist clasts. The aggregate is uncrushed and comparisons with crushed aggregate are difficult to make. However, the crushed equivalent is suggested to have a lower crushing resistance value (De Bock 1984), indicating that the aggregate is unsuitable for the production of a basecourse.

The use of the Northern Southland Transport aggregate as a roading aggregate is also restricted by the small grain size. The two grain size analyses completed by Bell (1980) demonstrate that less than 20% of the aggregate has a grain size of over 20 mm. This almost eliminated the use of this aggregate as an M/4 roading aggregate, because of the difficulty in obtaining an M/4 AP40 grading.

The clean nature of the aggregate is demonstrated by the high sand equivalent values, which may be attributable to the "washing" process that occur in the deltaic environment.

## 3.6 FARRY QUARRY.

### 3.6.1 Quarry Description.

The Farry quarry is located adjacent to the Queenstown-Glenorchy Road, 16km west of Queenstown on the uphill side of the road, on the true right bank of the Twelve Mile Creek and across the road from the Twelve Mile quarry (Fig 3.1). The quarry is owned by Mr P J Farry and aggregate from the quarry is used for sub-base and basecourse production within the Queenstown district. Mr Farry anticipates the quarry to be worked for a period of three years (Minutes of the Queenstown-Lakes District Council meeting 26 of February 1987). Aggregate production at the quarry involve scalping out the -9.5mm material and crushing the remaining aggregate (pers comm J R Bishop).

### 3.6.2 Engineering Geology

#### (i) Engineering Geological Description

The quarry exposes laminated to massive, sandy gravel mixtures. The deposit is laterally consistent, with no gross grain size variation. Particle shape of the aggregate is sub-angular to subrounded with about 20% of the particles having a discoidal or elongate shape (Table 3.1). A field description of the aggregate is as follows;

Light grey, unweathered, massive to bedded, SANDY fine to coarse GRAVEL with rare silt and cobbles (GW/GP).

compact-loose; dry; well to poorly graded; bedding sub-horizontal to moderately inclined, thin to thick; gravel sub-angular to subrounded, TZ II, III and IV schist, quartz and greywacke (5%); sand, fine to coarse; silt non-plastic; with occasional open textured gravel lenses and sand lenses.

#### (ii) Depositional Environment

The Farry quarry exposes a delta thought to have been ,

deposited after the retreat of the last glaciation. The deposit contains sedimentary structures such as open textured gravel lenses, occasional crude normal grading of lenses and moderately inclined foresets which suggest deposition in deltaic front environment.

### 3.6.3 Geotechnical Test Results.

Tests (Table 3.2) were carried out on crushed all-in aggregate samples collected from a crushing trial from the quarry (Lindsay 1987). The tests were carried out by R A Lindsay (1987) as part of a preliminary assessment of the quarry.

The preliminary crushing resistance result of 140kN suggests that the aggregate is within the crushing resistance limit for the NRB M/4 specification. Crushing resistance values, of 130kN also occasionally have been recorded at the Twelve Mile quarry, and are notably higher than crushing resistance values associated with schist derived aggregate of the Wakatipu Basin e.g. Shotover 100-110kN. The difference in crushing resistance values is suggested to be attributable to the Textural Zone II content (20%) of the Twelve Mile aggregate. It is postulated that schistosity is not as pronounced in Textural Zone II schist, as it is in Textural Zone III and IV. Therefore, samples with a Textural Zone II content will have a higher crushing resistance. Textural Zone II schist outcrops on the upthrown side of the Moonlight Fault (Fig. 1.3), and proportionally more Textural Zone II schist occurs in the aggregates of the Twelve Mile area.

Sand equivalent tests were not completed as field examination suggested that the cleanness of the material would be satisfactory (Lindsay 1987). This assumption seems

likely as the Twelve Mile quarry which exposes the same delta is clean, with sand equivalent values of 40 to 60.

Lindsay (1987) comments that the roading aggregate is suitable for use as a subbase, and will provide a satisfactory raw material for further processing to produce basecourse aggregate. A testing programme involving the full range of M/4 tests would have to be carried out to establish if the roading aggregate complies with the NRB M/4 specifications. However, preliminary tests suggest that the aggregate is capable of producing M/4 quality basecourse.

### 3.7 TWELVE MILE QUARRY

#### 3.7.1 Quarry Description

The quarry is located adjacent to the Queenstown-Glenorchy Road, 17km west of Queenstown, on the lake side of the road and on the true right bank of the Twelve Mile Creek (Fig. 3.1). The Twelve Mile quarry is owned by the Queenstown-Lakes District Council. The life expectancy of the quarry at present production rates is 2-3 years (pers comm L Matchett County Clerk).

Processing of aggregate from the Twelve Mile Quarry involves scalping out the -19mm fraction and then crushing the remaining aggregate (pers comm L. Matchett County <sup>Clerk</sup> Eng.) Scalping is completed in order to meet the NRB M/4 grading requirement. The Twelve Mile roading aggregate is used by Council for basecourse and sub-base construction around the Queenstown district.

#### 3.7.2 Engineering Geology.

##### (i) Engineering Geological Description

The Twelve Mile quarry exposes bedded, sandy gravel mixtures. The deposit is laterally consistent, and over the scale of the quarry does not show any gross grain size variation. Particle shape is subrounded to subangular with approximately 20% demonstrating a discoidal and elongate shape (Table 3.1). A field description of the deposit is provided below;

Light grey, unweathered, massive to bedded, SANDY fine to coarse GRAVEL with rare cobbles (GW/GP).

compact-loose; dry; well to poorly graded; bedding sub-horizontal to moderately inclined, thick to thin; gravel sub-angular to subrounded, Textural Zone II, III and IV schist, quartz and greywacke (10 %); sand, fine to coarse; silt non-plastic; with occasional open textured gravel lenses and gravely sand lenses.

#### (ii) Depositional Environment.

The Twelve Mile deposit is presumed to have been deposited as a delta which was built out into an enlarged Lake Wakatipu after the retreat of the last glaciation. The deposit contains sedimentary structures such as open textured gravel lenses, occasional crude normal grading of lenses and moderately inclined foresets which suggest deposition in a delta front environment.

The greywacke content (<5%) indicates that some of the Twelve Mile aggregate is glacial derived, probably from reworked kame terraces or till. Twelve Mile aggregate contains a higher percentage of Textural Zone II schist (20 %) than other aggregate deposits in the Wakatipu Basin. The Textural Zone II schist may have been glacially transported or locally derived, as Textural Zone II schist is exposed on the

downthrown side of the Moonlight Fault (Fig. 1.3).

### 3.7.3 Geotechnical Test Results.

Roading aggregate produced at the Twelve Mile quarry does not usually comply with NRB M/4 specifications (Table 3.2), because of low crushing resistance values in the range of 100-110kN (although occasional crushing resistance values of 130kN have been recorded). The Twelve Mile quarry is deltaic in origin, and as expected the aggregate contains minor (< 5%) silt and clay. This "cleanness" of the aggregate is reflected in the high sand equivalent values e.g. 40-60.

## 3.8 TWENTY FIVE MILE QUARRY

### 3.8.1 Quarry Description

The Twenty Five Mile quarry is located adjacent to the Queenstown-Glenorchy Road, 30km west of Queenstown, on the uphill side of the road, and on the true right bank of the Twenty Five Mile Creek (Fig. 3.1). The Twenty Five Mile quarry is owned by the Queenstown-Lakes District Council.

The aggregate is used for subbase and basecourse construction and maintenance of the unsealed Queenstown-Glenorchy Road in the vicinity of the Twenty Five Mile quarry.

### 3.8.2 Engineering Geology

#### (i) Engineering Geology Description

The Twenty Five Mile quarry exposes bedded, sandy gravel mixtures. The deposit is laterally consistent over the scale of the quarry and does not show any gross grain size variation. Particle shape is subrounded to suban-



gular, with approximately 20% demonstrating a discoidal and elongate shape (Table 3.3). A field description of aggregate from the quarry is as follows;

Light grey, unweathered, massive to bedded, SANDY fine to coarse GRAVEL with rare cobbles (GW/GM).

compact-loose; dry; well to poorly graded; bedding sub-horizontal to moderately inclined, thick to thin; gravel sub-angular to subrounded, Textural Zone II, III and IV schist and quartz; sand, fine to coarse; silt non-plastic; with occasional open textured gravel lenses and gravely sand lenses.

#### (ii) Depositional Environment

Twenty Five Mile deposit is thought to be a delta, which was deposited after the retreat of the last glaciation. The Twenty Five Mile delta represents the +25m lake level, which is prominent throughout the Wakatipu Basin. Many examples of +45 m and +25 m deltas are evident along the Queenstown-Glenorchy Road.

No greywacke is identified within the deposit, this may be explained by (a) during formation of the delta no glacial material was reworked or (b) during formation of the delta no greywacke rich glacial material was present within the Twenty Five Mile Creek catchment. The second explanation seems the more likely, as the Caples Group rocks outcrop on the adjacent side of Lake Wakatipu (Fig. 1.3), making glacial transport of the greywacke rich material to the Twenty Five Mile area difficult to envisage. It would seem likely that the greywacke rich glacial material presumably lateral and medial moraine, was restricted to the western side of the lake at least until about the Twelve Mile area.

### 3.8.3 Geotechnical Test Results.

No M/4 tests have been carried out on Twenty Five aggregate. The Twenty Five Mile and the Twelve Mile aggregates, have similar environments of deposition and descriptions, but the Twelve Mile has a greywacke and Textural Zone II content. Therefore, it is envisaged that the Twenty Five Mile quarry is capable of producing roading aggregate of similar quality to the Twelve Mile quarry, but with a lower crushing resistance.

## 3.9 ARTHURS POINT QUARRY

### 3.9.1 Quarry Description

The Arthurs Point quarry is located on the true right bank of the Shotover River, upstream of Arthurs Point (Fig. 3.1). The quarry is owned by the Council.

### 3.9.2 Engineering Geology

#### (i) Engineering Geology Description

The Arthurs Point quarry exposes a massive to crudely bedded sandy gravel mixtures. Over the scale of the deposit no gross grain size variation was recognized. Particle shape is subrounded to subangular, with approximately 20% demonstrating a discoidal and elongate shape (Table 3.1). A field description of the aggregate is as follows;

Light grey, unweathered, massive to crudely bedded, SANDY fine to coarse GRAVEL with some cobbles and rare silt (GW/GP).

compact-loose; dry; well to poorly graded; bedding sub-horizontal to moderately inclined, thick to thin; gravel sub-

angular to subrounded, Textural Zone III and IV schist and quartz; sand, fine to coarse; silt non-plastic; with occasional open textured gravel lenses and gravelly sand lenses.

(ii) Depositional Environment.

The depositional environment of the quarry is not clear, as glacial and post-glacial events in the Arthurs Point region are complex. However, the quarry is suggested to be deltaic and form part of the Shotover delta deposited after the retreat of the last glaciation.

### 3.9.3 Geotechnical Test Results.

No M/4 test results have been carried out on Arthurs Point aggregate. However, the aggregate has a similar description and depositional environment to the Tuckers Beach aggregate, therefore similar aggregate quality is also suggested (see section 3.10).

## 3.10 QUEENSTOWN-LAKES DISTRICT COUNCIL GRAVEL LICENCES

### 3.10.1 General

Gravel licences are granted by the Otago Catchment Board, and allow the holder of the licence to remove aggregate from an approved area for a period of one year. From the 11 November 1985 to 11 November 1986 the Queenstown-Lakes District Council held five gravel licence within the Wakatipu Basin (pers comm L Matchett, County Clerk). These licences, along with one held in 1984 (the Glacier Burn licence from which stock piled aggregate is still being used), are discussed within this section. The discussion includes a

description of the licence, an engineering geological description of the aggregate and interpretation of any geotechnical test results.

### 3.10.2 Engineering Geology of Gravel Licences.

Aggregate from the gravel licences can generally be described as sandy gravel mixtures. A typical field description of the gravel licence aggregate is as follows:

Light grey, unweathered, massive, SANDY fine to course GRAVEL (GW/GP).

loose; well to poorly graded; gravel subangular to sub-rounded, TZ II, III and IV schist and quartz; sand, fine to coarse.

The only difference between the gravel licence descriptions is the particle shape and lithology of the gravel fraction. A general description, lithology of the gravel fraction, and particle shape of the aggregate from each of the gravel licences is presented in Table 3.4. The gravel licence aggregate is deposited by river action, and has been "washed", with only minor amounts (<5%) of silt present, hence sand equivalent values are inferred to be of M/4 quality. Crushing resistance values of the gravel licences are suggested to be variable, depending on the greywacke content.

### 3.3.3 Tucker's Beach

#### (i) Licence Description

The licence is located on the true right bank of the Shotover River, up stream from the Shotover bridge (Fig. 3.1). The amount of aggregate licensed to be removed is 2000m<sup>3</sup> a year. Aggregate is removed from the water's edge

Gravel Licence	General Description	Lithology of Gravel Fraction	Particle Shape
Tucker's Beach	Sandy fine to coarse Gravel	TZ III, IV and quartz	Subangular-subrounded 20% discoidal
Buckler Burn	Sandy fine to coarse Gravel	TZ III, IV and quartz	Subangular-subrounded 20% discoidal
Precipice Creek	Sandy fine to coarse Gravel	TZ III, IV and quartz	Subangular-subrounded 10% discoidal
Rees River	Sandy fine to coarse Gravel	TZ III, IV and quartz	Subangular-subrounded 20% discoidal
Dart River Bridge	Sandy fine to coarse Gravel	TZ II, III, quartz and greywacke 20-30%	Subangular-subrounded 30% discoidal
Dart River	Sandy fine to coarse Gravel	TZ II, III, quartz and greywacke 20-30%	Subangular-subrounded 30% discoidal
Glacier Burn	Sandy fine to coarse Gravel	TZ II, III, quartz and greywacke 20-30%	Subangular-subrounded 30% discoidal

Table 3.4 Data summary of Queenstown-Lakes District Council gravel licences.

parallel to the true right bank of the river, in order to leave a regular alignment.

Tuckers Beach aggregate is screened and crushed, and the scalping size is usually -19mm (pers comm L Matchett County Clerk). The roading aggregate is used for sub-base and general roading purposes within the Queenstown area (pers comm County Clerk).

#### (ii) Geotechnical Test Results

Test results carried out on aggregate from the Tuckers Beach area are presented in Table 3.2. Crushing resistance values (90-100kN) of roading aggregate from the licence do not comply with NRB M/4 specification and demonstrates the typical weak nature of the schist-derived aggregate (Table 3.2). The roading aggregate is clean and has no problem meeting the required sand equivalent value.

The Ministry of Works and Development also uses roading aggregate produced from the Tuckers Beach area, and Wathey (1984) comments that the roading aggregate was of poor quality, and that by 1966 the better quality material had been worked out. Since 1966 only small amounts of roading aggregate from the source have been used by the MOW as filter material, drainage layers and shoulder dressing (Wathey 1984). Wathey (1984) recommends that, due to the weak nature of the lower Shotover roading aggregate, it only be used as a sub-base on a strong subgrade or as a filter layer.

#### 3.10.4 Buckler Burn

##### (i) Licence Description

The licence is located in the Buckler Burn, down stream of the Buckler Burn Bridge (Fig. 3.1). The amount of aggre-

gate licensed to be removed is  $2000\text{m}^3$  a year. Gravel is not to be removed from the natural banks of the stream. The aggregate is screened and crushed and used for local roading requirements (pres comm L. Matchett, County Clerk).

(ii) Geotechnical Test Results

No tests have been carried out on roading aggregate from the licence. However, sufficient similarities exist between the Buckler Burn and the Twelve Mile aggregate to suggest that the two roading aggregates will have similar properties. No greywacke or Textural Zone II schist was identified within the Buckler Burn aggregate, therefore the Buckler Burn aggregate may produce lower crushing resistance values.

3.10.5 Precipice Creek

(i) Licence Description

The licence is located in the Precipice Creek bed, upstream and downstream of the Precipice Creek Bridge (Fig. 3.1). The amount of aggregate licensed to be removed from the creekbed is  $2000\text{m}^3$  a year. Beach skimming methods are to be employed to remove aggregate. The aggregate is screened and sometimes crushed for local roading purposes (pers comm L Matchett, County Clerk).

(ii) Geotechnical Test Results

No test have been completed on the Precipice Creek roading aggregate. However, the aggregate contains no greywacke content and crushing resistance values are suggested to be of sub-M/4 standard.

### 3.10.6 Rees River

#### (i) Licence Description

The licence is located in the Rees River, approximately 200 m downstream of the Rees River bridge (Fig. 3.1). The amount of aggregate licensed to be removed from the creekbed is 2000m<sup>3</sup> a year. Beach skimming methods are to be employed to remove aggregate. The aggregate is screened and sometimes crushed for local roading purposes (pers comm L Matchett, County Clerk).

#### (ii) Geotechnical Test Results

No tests have been completed on the Rees River roading aggregate. However, the aggregate contains no greywacke content and crushing resistance values are suggested to be of sub-M/4 standard.

### 3.10.7 Dart River Bridge

#### (i) Licence Description

The licence is located in the Dart River, approximately 100 m downstream of the Dart River bridge (Fig. 3.1). The amount of aggregate licensed to be removed from the creekbed is 2000m<sup>3</sup> a year. Beach skimming methods as far as possible from the natural river banks are to be employed to remove aggregate. Aggregate from the Dart River is screened and crushed for local roading requirements (pres comm L Matchett, County Clerk).

#### (ii) Geotechnical Test Results

Test results of the Dart River roading aggregate are presented in Table 3.1. The limited results indicate a clean aggregate with higher abrasion resistance values than schist



derived aggregates of the Wakatipu Basin. The abrasion resistance values of 34-38% are inferred to be attributable to the greywacke content.

### 3.10.8 Dart River

#### (i) Licence Description

The licence is located in the Dart River, approximately 7km upstream of the Dart River bridge (Fig. 3.1). The amount of aggregate licensed to be removed from the riverbed is 4000m<sup>3</sup> a year. Beach skimming methods as far as possible from the natural river banks are to be employed to remove aggregate. Aggregate from the licence is screened and crushed for local roading requirements (pers comm L. Matchett).

#### (ii) Geotechnical Test Results

No tests have been completed on aggregate or roading aggregate from the licence. However, aggregate from the licence has a similar description and source rocks to the Dart River Bridge aggregate, and it is expected that the two aggregates will have similar properties.

### 3.10.9 Glacier Burn

#### (i) Licence Description

The licence is located within the Glacier Burn, approximately 50 m upstream of Kinlock Road (Fig. 3.1). The amount of aggregate licensed to be removed from the riverbed is 2000m<sup>3</sup> a year. Beach skimming methods are to be employed to remove aggregate. Aggregate from the licence is screened and crushed for local roading requirements (pers comm L. Matchett).

### (ii) Geotechnical Test Results

No tests have been completed on aggregate or roading aggregate from the licence. However, because of the greywacke content it is envisaged that the aggregate would produce a strong roading aggregate with a crushing resistance of over 130kN.

### 3.11 SYNTHESIS

Evaluation of existing roading aggregate resources, confirms that there is no major source of NRB M/4 quality aggregate within the Wakatipu Basin, and that the Lumberbox quarry (which the Ministry of Works and Development own and have the restricted use of) is the only major source of aggregate suitable for basecourse production.

Eight aggregate quarries intermittently produce roading aggregate within the Wakatipu Basin. The existing aggregate quarries and the deposit they expose are as follows:

- (a) Lumberbox - fan-delta complex;
- (b) Two Mile - fan-delta complex;
- (c) Mt Cook Group - kame terraces;
- (d) Northern Southland Transport - delta;
- (e) Farry - delta;
- (f) Twelve Mile - delta;
- (g) Twenty Five Mile - delta; and

Existing aggregate sources can generally be divided into two major groups; (a) schist derived aggregate and (b) schist and Caples-derived aggregate. Schist-derived aggregate usually produces roading aggregate that fails to meet the M/4 crushing resistance requirement, with the exception of the

Twelve Mile aggregate which has occasionally produced crushing resistance values of 130 and 140kN. The poor quality (100-110kN) is attributable to the inherent schistosity which produces a weak, easily cleaved aggregate, which may produce elongated or discoidal shaped clasts.

Mixed schist and greywacke (> 10%) derived aggregate usually meets the required crushing resistance value, which is suggested to be related to the greywacke content, as demonstrated by Fig. 3.2. The highest quality roading aggregate of the Wakatipu Basin is produced at the Lumberbox quarry, a schist and greywacke derived aggregate. The roading aggregate fails to comply with the M/4 sand equivalent requirement, however the Wakatipu Test Sections and local roading experience (Wathey 1984) have demonstrated that the low sand equivalent values do not affect the performance of the roading aggregate.

Limited geotechnical tests indicate that the Two Mile and Farry quarries are capable of producing roading aggregate that complies with the NRB M/4 specification. However, the expected quarry life of both quarries is limited, and would not be sufficient to meet future Queenstown-Lakes District Council roading aggregate requirements.

Aggregate that is expected to be capable of producing M/4 quality roading aggregate is present within the Dart and Glacier Burn Gravel Licences. The aggregate is a mixed schist and greywacke-derived aggregate, and the greywacke content is presumed to be capable of producing M/4 crushing resistance values. The "washing" effect of the river deposition suggests the aggregate will be clean and be capable of producing M/4 sand equivalent values. However, the use of these sources is limited by the cost of transporting the

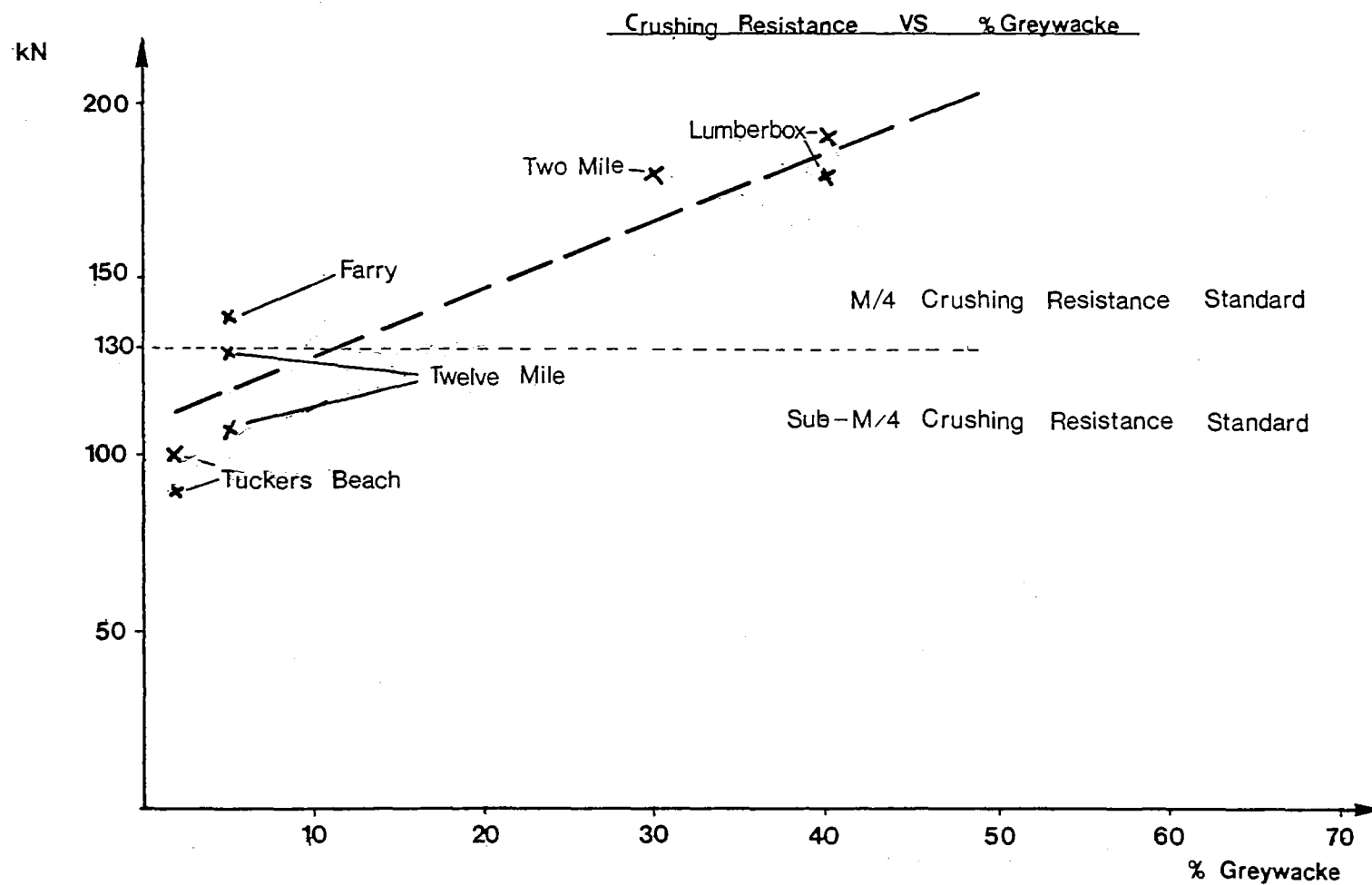


Fig. 3.2 The relationship between crushing resistance and greywacke content of crushed roading aggregate of the Wakatipu Basin.

aggregate 80km to the Queenstown area.

## CHAPTER FOUR

## AGGREGATE SURVEY

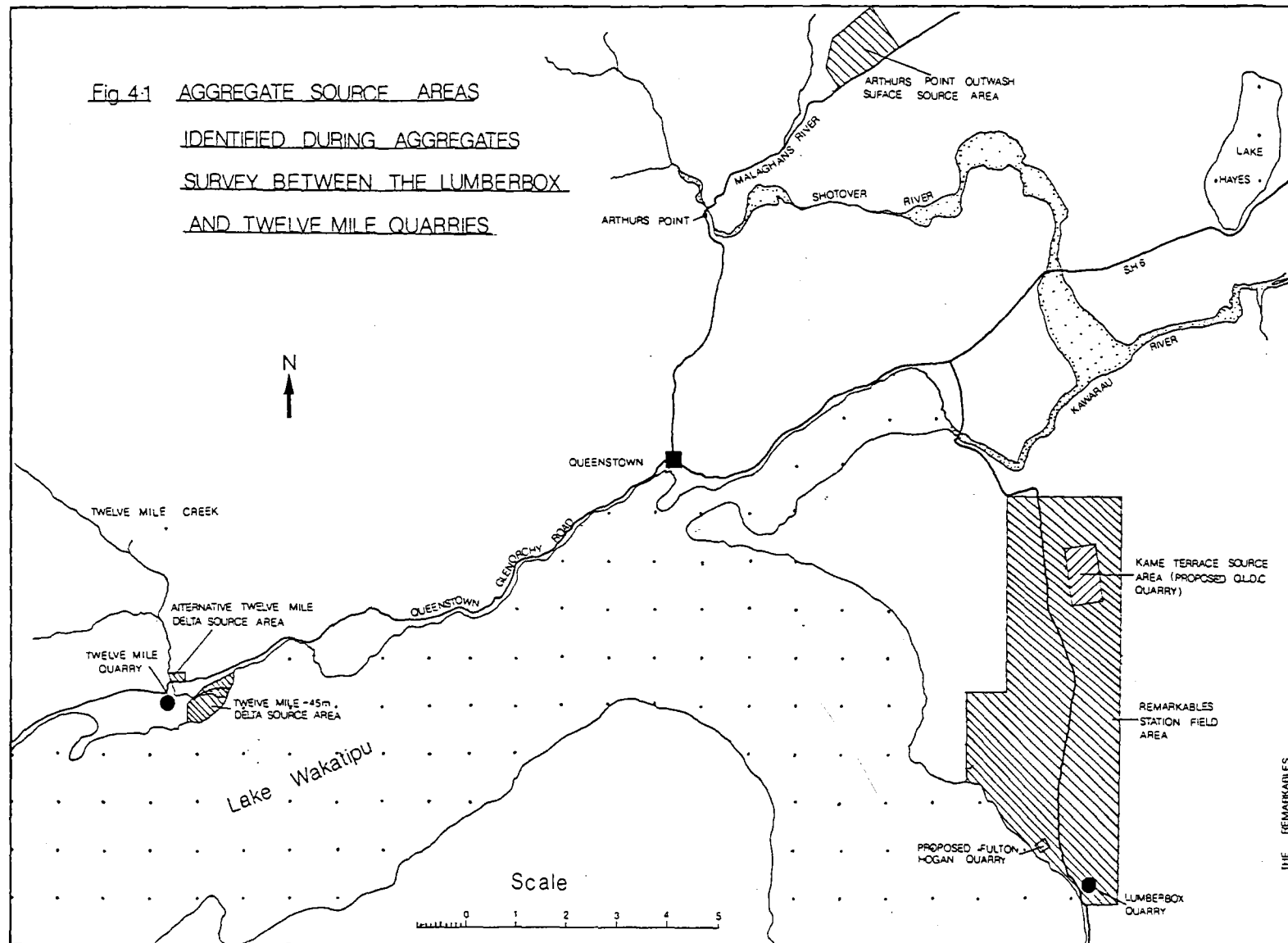
## 4.1 INTRODUCTION

In general, two types of roading aggregate occur within the Wakatipu Basin; (a) schist-derived roading aggregate (e.g. Twelve Mile Quarry), and (b) mixed schist and greywacke roading aggregate (e.g. Lumberbox Quarry). As detailed in chapter 3, neither type of roading aggregate complies with NRB M/4 specifications, however the schist and greywacke-derived aggregate produces the highest quality roading aggregate, with crushing resistance values of M/4 standard. The additional strength of these aggregate sources is attributable to the strong non-schistose "greywacke" content of the greywacke (ie. Caples Group).

To locate aggregate source areas of suitable quality, the aggregate survey between the geographical limits of the Lumberbox and Twelve Mile quarries was therefore, restricted to source areas which contained either a percentage of greywacke or schist-derived aggregate which had demonstrated NRB M/4 crushing resistance.

During field work for the aggregate survey, four potential aggregate source areas have been identified (Fig. 4.1) within the geographical limits of the Twelve Mile and Lumberbox quarry, these include:-

- (a) Kame terraces on the lower western slopes of The Remarkables;
- (b) Twelve Mile +45m Delta;



- (c) Alternative Twelve Mile Delta; and
- (e) Arthurs Point outwash surface.

Also, during field work for the aggregate survey, a section of The Remarkables Station was mapped and from this field work the kame terrace source area was identified (Fig.4.1). The Queenstown-Lakes District Council initiated further investigations of the kame terrace and Twelve Mile +45m source areas.

Seven source areas have been identified along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads and at the completion of this thesis study no further investigations of the source areas had been initiated by the Queenstown-Lakes District Council (Fig. 4.10).

In this chapter, engineering geological investigations carried out on the source areas identified in the aggregate survey are described and discussed.

Council was also invited to tender for the right to quarry an area of the The Remarkables Station property (Fig. 4.1). The engineering geological investigation involved in assessing the tender is described and discussed in this chapter.

## 4.2 REMARKABLES STATION

### 4.2.1 General

In an effort to locate a source area that contained a percentage of greywacke, a section of The Remarkables station that contains glacial deposits was investigated (Fig. 4.1). This area is also of interest because several aggregate quarries (Fig. 4.2) occur within the area, including:-



- (a) Mt. Cook Group quarries;
- (b) Northern Southland Transport quarry;
- (c) Lumberbox quarry;
- (e) Proposed Fulton Hogan Ltd. quarry;
- (f) Disused concrete aggregate quarry; and
- (g) Borrow pit used for roading aggregate on the Coronet Peak road.

#### 4.2.2 Site Investigations

A base map of the field area was prepared by enlarging the N.Z.M.S.1 series sheet 132 to a scale of 1:10000. The field area was mapped using exposures, geomorphology and aerial photos, an engineering geological plan was prepared at the scale of 1:10000, along with an engineering geological cross sections at the scale of 1:50000 (Fig. 4.2).

#### 4.2.3 Geology

Eight geological units have been identified in the field area (Table 4.1). The relative positions of these units are represented on the plan and cross sections of Fig. 4.2. Textural Zone IV Haast Schist and seven Quaternary deposits are identified within the field area. The Quaternary deposits include, three glacial (Otiran) and four post-glacial deposits. The glacial deposits include Otiran alluvial fans, kame terraces and ablation and lodgement till. Due to the limited exposures and the scale of the engineering geological plan, lodgement and ablation till are mapped as one unit. The post-glacial deposits include fan-delta complexes, deltas, alluvial fans and lake sediment. Field descriptions of the units are provided in Appendix 2.

Lodgment and ablation till are inferred to overlie

Geological Unit	Relative Age
Lake sediment	post-glacial (Aranian)
Delta	
Fan-delta complex	
Kame terraces	glacial (Otiran)
Otiran Alluvial Fan	
Haast Schist TZ IV	Permian-Triassic?

Table 4.1 Relative age of geological units  
identified at The Remarkables  
Station field area.

schist basement and underlie all other deposits (Fig. 4.2). Exposures indicate that lodgement till has a thickness of 0.5-2m. The thickness of the ablation till is inferred from exposures to be greater than 20m in some locations.

Otiran alluvial fans are overlain by kame terraces (Fig. 4.2), and exposures show that the Otiran alluvial fan is at least 10m in thickness. Kame terraces are underlain by Otiran alluvial fans and are also expected to be underlain by lodgement till (Fig. 4.2). The thickness of the kame terraces varies from a measured thickness of 2m to an inferred thickness from exposures of at least 10m.

Fan-delta complex and deltas occur as an almost continual band of sediment at the base of The Remarkables and along the shore of Lake Wakatipu (Fig. 4.2). The measured thickness of the fan-delta complexes and deltas varies from 2m to 20m.

Lake sediment is inferred to overlie lodgement and ablation till. The lake sediment has a measured thickness of 2m, but is predicted to have a thickness of greater than 5m in some locations. Alluvial fans overlie kame terraces, and have a measured thickness of 4m, but where stream activity has been greater the thickness is predicted to be at least 10m.

#### 4.2.4 Existing Aggregate Quarries

Three quarries are presently producing aggregate within the field area of Fig. 4.2. They are the Lumberbox, Mount Cook Group, and Northern Southland Transport quarries. The Lumberbox is quarrying fan-delta complex aggregate, the Mount Cook Group is quarrying kame terrace material, and Northern Southland Transport is quarrying deltaic aggregate. These aggregate quarries have been described and discussed in chapter 3.

Two presently unused aggregate quarries also occur in the field area of Fig. 4.2, but they have not been described. They are:-

(a) Coronet Peak Road borrow pit.

The Coronet Peak Road borrow pit exposes "reworked" ablation till (Fig. 4.2). Aggregate was excavated and used for basecourse during completion of the upper section of the Coronet Peak Road (pers comm D. Jardine). As excavation was extended it was found that the material became silty and the borrow pit was discontinued (pers comm D. Jardine). The "reworked" ablation till in this location is generally coarser and has less silt than ablation till described from other exposures. It is envisaged that ablation till in this location has been reworked by streams or a higher lake level, and therefore has had some of the fines "washed out". A field description of the aggregate is as follows:

Sand Gravel

Light grey, unweathered, massive, Sandy fine to coarse Gravel with some silt (GM).

-loose to compact; well to poorly graded; moist; gravel, schist TZ III, IV, and II and 30-40% greywacke, sub-angular to rounded; sand fine to coarse.

(b) Concrete Aggregate Quarry.

A disused concrete quarry is located on the shore of Lake Wakatipu (Fig. 4.2). The quarry is located within a deltaic deposit, deposited when Lake Wakatipu was approximately 8m above its present level. A description of the aggregate is as follows:

Sand Gravel

Light grey, unweathered, bedded, Sandy fine to medium

Gravel (GP).

-loose; poorly graded; moist; bedding, sub-horizontal to moderately inclined, thin to moderately thin; gravel, schist TZ III, IV, and II and 20-30% greywacke, subangular to rounded; sand fine to coarse; occasional gravel lenses and sand lenses.

#### 4.2.5 Aggregate Sources within Field Area

Ablation till is not considered as a potential aggregate source area because of the typically high silt content till (as discussed in section 2.5.1). Reworked ablation till similar to that found at the Coronet Peak Road borrow pit was not considered as a aggregate source because it was envisaged that an insufficient quantity (ie.  $<10000\text{m}^3$ ) of aggregate was available.

Five aggregate sources (identified and discussed in section 2.6) are exposed in The Remarkables Station field area (Fig. 4.2). These include:-

- (a) Otiran alluvial fans;
- (b) Kame terraces;
- (c) Deltas;
- (d) Fan-delta complexes; and
- (e) Alluvial fans.

Otiran alluvial fans within the field area consist of schist and quartz gravel mixtures which can be described as fine to coarse gravel with some sand. Otiran alluvial fans contain no greywacke and are suggested to produce sub-M/4 standard roading aggregate with crushing resistance values of less than 130kN.

Kame terraces consist of sandy fine to coarse gravel with some silt mixtures which contain schist, quartz and

greywacke (20-30%). Kame terrace aggregate is inferred to produce M/4 quality crushing resistance values as the aggregate contains 20-30% greywacke.

Fan-delta complexes within the field area consist of sandy fine to medium gravel mixtures which contain schist, quartz and greywacke (10-30%). The aggregate does not contain coarse size gravel fraction (ie. >20mm) required for the production of M/4 AP40, except for the area presently quarried at the Lumberbox. The difference in grain size within the fan-delta complex is suggested to be related to the proximal location of the Lumberbox aggregate within the complex (discussed further in section 2.5.5).

Delta deposits within the field area consist of sandy fine to medium gravel mixtures which contain schist, quartz and greywacke (5-30%). The deltaic aggregate is of similar grain size to the fan-delta complexes, and does not contain coarse grained gravel fraction (ie. >20mm) required for the production of M/4 AP40.

Alluvial fans within the field area consist of sandy fine to coarse gravel mixtures which contain schist, quartz and greywacke (5-20%). The greywacke content of the alluvial fans is suggested to produce M/4 quality crushing resistance values.

Of the five aggregate sources within the field area, alluvial fan and kame terrace aggregate sources are inferred to be capable of producing the highest quality roading aggregate. Kame terrace aggregate has a higher greywacke content than the alluvial aggregate, therefore the kame terrace material was suggested in a report to Council as a potential aggregate source area (Watts 1986, report provided in Appendix 3). The northern extension of the kame terraces occur as

a well defined flight of terraces (Fig. 4.3), further to the south the terraces have been reworked by recent stream activity, but still contain some of the original terrace geomorphology (Fig. 4.4). Therefore the northern extension of the kame terraces was suggested as a possible source area, however if the source area proves to be unsuitable, the southern extension should be investigated.

#### 4.3 KAME TERRACE SOURCE AREA.

##### 4.3.1 General.

Queenstown-Lakes District Council acting on the "Preliminary Report on the Wakatipu Aggregate Survey Investigations to Date" (Watts 1986, provided in Appendix 3) instructed Duffill Watts and King Ltd. to take appropriate steps to further investigate the kame terraces. Land incorporating kame terraces is owned by seven land owners and due to difficulty involved in acquiring the mining rights from seven land owners, kame terraces further to the south were investigated, this alternative having been suggested in the preliminary report to Council. Duffill Watts and King arranged consent from D. Jardine to carry out investigations to establish the quality and quantity of aggregate available in the kame terrace source area (Fig. 4.1).

##### 4.3.2 Site Description.

The site is located on the lower westerly slopes of The Remarkables (Fig. 4.1). The site is approximately 60 hec-



Fig. 4.3 Northern extension of kame terraces within the Remarkables Station field area, note the well defined terraces.



Fig. 4.4 Southern extension of kame terraces within The Remarkables Station field area, note the reworking by alluvial fans.



tares and is 500m east of State Highway Six (Fig. 4.2). Four geological units were identified, two glacial (Otiran) and two post-glacial. The two glacial units include kame terrace and till deposits and the two post-glacial units include delta and fan alluvium deposits.

The topography is dominated by two kame terraces which run parallel to each other from north to south (Fig. 4.5). Overprinted on these terraces are gently sloping alluvial fans. In the southern part of the site the fan material has almost completely modified the terraces, with only a slight topographical expression of the terrace definable (Fig. 4.4). These fans have been deposited by three ephemeral streams which cut across the terraces at approximately  $90^{\circ}$ .

#### 4.3.3 Site Investigations

##### (i) Engineering Geological Mapping.

The kame terrace deposits were surveyed using a theodolite, and distances were calculated using stadia information. The survey data were reduced using the Geology Department's Texas survey reduction computer programme. From the reduced data a topographical map was prepared at a scale of 1:1500. An arbitrary datum was used, estimated from the N.Z.M.S.1 series sheet 132.

##### (ii) Test Pits and Sampling

The site has been mapped and an engineering geological plan and cross sections prepared at a scale of 1:1500 (Fig. 4.5). The purpose of the mapping was to identify the distribution and thickness of geological units. Exposures, geomorphology and aerial photos were used to map the site.

Thirteen test pits were excavated and logged to provide

subsurface information for mapping, and for the collection of channel samples. Summary logs of test pits are provided on Fig. 4.5, and detailed logs in Appendix 4. Nineteen channel samples were collected, two of these having been tested by the Ministry of Works and Development in Alexandra for grading, sand equivalent and crushing resistance (see section 5.8.1 for results). These results suggested that the kame terrace and alluvial fan material are capable of producing basecourse roading aggregate. Therefore, a 40m<sup>3</sup> crushing trial was excavated from test pit 13 to further investigate the aggregate quality.

The crushing trial was excavated from alluvial fan material, because the loader and truck used to load and transport the aggregate were only able to obtain access to the alluvial fan aggregate. The bulk sample collected for the crushing trial had a description similar to alluvial fan aggregate exposed in other test pits and was thought to be representative of the alluvial material. From the crushing trial six crushed aggregate samples were collected (discussed further in section 5.2).

#### 4.3.4 Geology

##### (i) Lodgement and Ablation Till

Till is exposed in test pits 11 and 12 (Fig. 4.5), and from the field description and relative position the till is inferred to be ablation till. Lodgement till is inferred to underlie kame terraces. No field distinction between ablation and lodgement till was possible due to the limited exposures. Ablation till exposed in test pit 11 and 12 consists of a massive Silt/Sand/Gravel with approximately 30-40% greywacke. A lithological analysis and particle size distribution of an

ablation till sample has been carried out, and the results are discussed in chapter five. The grain size distribution indicates that the ablation till has a high silt and sand content, and is not suitable for the basecourse production.

Lodgement and ablation till is of an unknown thickness, but is suggested to have a combined thickness of up to 20m in some locations, and is inferred to underlie the other three units and overlie schist basement (Fig. 4.5).

#### (ii) Kame Terrace.

Kame terrace aggregate typically consists of sandy fine to coarse gravel with some silt, and contains between 5-30% greywacke. Particle shape of the aggregate is subangular to rounded, with approximately 10% of the clasts demonstrating discoidal or elongate shape.

The kame terrace material is inferred to overlie till at a depth of less than 20m (Fig. 4.5). Test pits 2,3,4,5 and 6 demonstrate that the kame terrace material is greater than 4m in thickness (Fig. 4.5), and exposures indicate a thickness of greater than 10m. The grain size of the kame terrace aggregate is variable and include silt and till lenses, and therefore it is envisaged that the aggregate will have to be scalped to remove the unwanted finer (<75um) material.

#### (iii) Delta .

The deltaic aggregate consists of sandy fine to medium gravel and contains approximately 5% greywacke. Particle shape of the aggregate is subangular to subrounded, with approximately 20% of the clasts demonstrating discoidal or elongate shape. The offal pit outcrop (Fig. 4.5) indicates that the deltaic material is greater than 4m in thickness.

The greywacke content of the deltaic aggregate is 5%, which is typically less than the kame terrace and alluvial fan aggregate from which the deltaic aggregate is inferred to be derived from. However, the aggregate is suggested to be diluted by schist-derived aggregate from the catchments above.

The delta material contains approximately 10-20% of coarse gravel fraction (ie. >20mm), therefore making the aggregate unsuitable for the production of M/4 AP40. The greywacke content of the deltaic aggregate suggests that crushing resistance values will be sub-M/4 standard. Deltaic aggregate exposed at the Northern Southland Transport aggregate quarry (Fig. 4.2) has substandard crushing resistance, and only contains 10-20% of the coarse gravel fraction (Bell 1980), which is unsuitable for the production of M/4 AP40.

(iv) Alluvial Fan.

The alluvial fan aggregate typically consists of sandy fine to coarse gravel with rare silt and contains between 5-20% greywacke. The alluvial fan overlies the other three deposits (Fig. 4.5). Test pits demonstrate that the alluvium is less than 4m in thickness, however test pit 9 indicated that in certain places the alluvium is greater than 4m in thickness (Fig. 4.5).

The alluvial fan material is considered suitable for the production of roading aggregate because it contains coarse aggregate suitable for crushing, and has a greywacke content of between 5-20%.

#### 4.3.5 Proposed Queenstown-Lakes District Council Aggregate Quarry within the Kame Terrace Source Area

##### (i) Quality

The quality of roading aggregate produced from kame terrace source area is suggested to have similar geotechnical properties to roading aggregate produced at the Lumberbox quarry. The Lumberbox quarry produces the highest quality within the Wakatipu Basin (geotechnical results discussed in chapter 5).

##### (ii) Quantity.

A conservative estimate of aggregate available from the proposed quarry site is  $900000\text{m}^3$  (insitu), based on the following calculation:-

A rectangle defined by test pit 1, 10, 9, and 3 (Fig. 4.5) which has the dimensions of  $300\text{m} \times 800\text{m}$ , contains kame and alluvial aggregate to an average depth of  $4\text{m}$  (indicated by the test pits), therefore, the estimated quantity of insitu aggregate is  $960000\text{m}^3$ .

The proposed quarry is suggested to be able to meet Councils total roading aggregate requirements for approximately twenty years, based on the following assumptions:-

(a) An insitu density of  $2.1\text{ t/m}^3$ , and a loose density of  $1.5\text{ t/m}^3$ , an estimate of the loose volume of aggregate is  $1344000\text{m}^3$ .

(b) If an average of 50% of the aggregate is to be scalped out (estimation of scalping discussed in chapter 5), then the estimated loose volume of aggregate available is  $672000\text{m}^3$ .

(c) The Queenstown-Lakes District Council uses approximately  $30000\text{m}^3$  (loose measurement) annually (pers comm R.

Duff, County Engineer) therefore, the proposed quarry would be able to meet Council's total roading aggregate requirements (ie. at present production rates) for approximately twenty years.

#### (iii) Aggregate Quarry

Based on the above information supplied by the author, Council decided to take appropriate steps to develop an aggregate quarry within the kame terrace source area, quarrying both the kame terrace and alluvial fan aggregate. Council sought planning approval for the aggregate quarry, which required the submission of a Management Plan (Watts 1987, provided in Appendix 5) for a Town and Country Planning hearing.

The application was consented to subject to ten conditions which are given in Appendix 6).

A contract to construct the access track and layby from State Highway Six for the quarry has been completed. A quarrying and crushing contract at the Queenstown-Lakes District Council aggregate quarry has been prepared by Duffill Watts and King Ltd. The contract involves formation of an access road, opening up of the quarry operation and aggregate production. The quarrying and crushing contract is provided in Appendix 7. At the completion of this thesis the contract had not been leased.

### 4.4 TWELVE MILE +45m DELTA SOURCE AREA

#### 4.4.1 General

Although the Twelve Mile delta aggregate has only a

minor amount (5%) of greywacke, crushing resistance values of 130-140kN have been recorded within the Twelve Mile area (Lindsay 1987), therefore, the delta material was considered as a potential source area. The aggregate source was identified and suggested to Council in the "Preliminary Report on the Wakatipu Aggregate Survey Investigations to Date" (Watts 1986, provided in Appendix 3).

#### 4.4.2 Site Description

The site is located on the lake side of the Queenstown-Glenorchy Road on both sides of the Twelve Mile Creek mouth (see Fig. 4.1), and occupies 81.7ha of the Mid Wakatipu Recreational Reserve. The site is bounded to the east and south by Lake Wakatipu, the northern and western boundaries being surveyed boundaries (Fig. 4.6).

The potential source area is dominated by a +45m delta (Fig. 4.7). In the past, gold mining has been active within the +45m delta aggregate and gold tailings and sluicing are recognisable. The 20m high scarp identified in Fig. 4.6 has been formed by the Twelve Mile Creek undercutting and eroding the +45m delta.

#### 4.4.3 Site Investigations

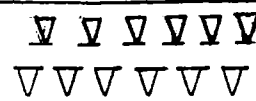
A plan of the Twelve Mile Creek Mining Licence Application, prepared by Lucy and Borrel (Registered Surveyors) at the scale of 1:5000 was used as a base map for an engineering geological map of the Twelve Mile +45m delta deposit (Fig. 4.6).

Only the site's boundaries and the position of the Twelve Mile Creek were surveyed by Lucy and Borrel. No contour information was available and the position of the con-

## ENGINEERING GEOLOGY LEGEND

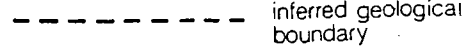


DELTA  
Sandy fine to coarse  
Gravel



convex break in  
slope  
concave break  
in slope

break in slope  
representing  
paleo - lake levels



inferred geological  
boundary



erosion scarpe formed  
by creek undercutting



SCHIST  
Textural zone II

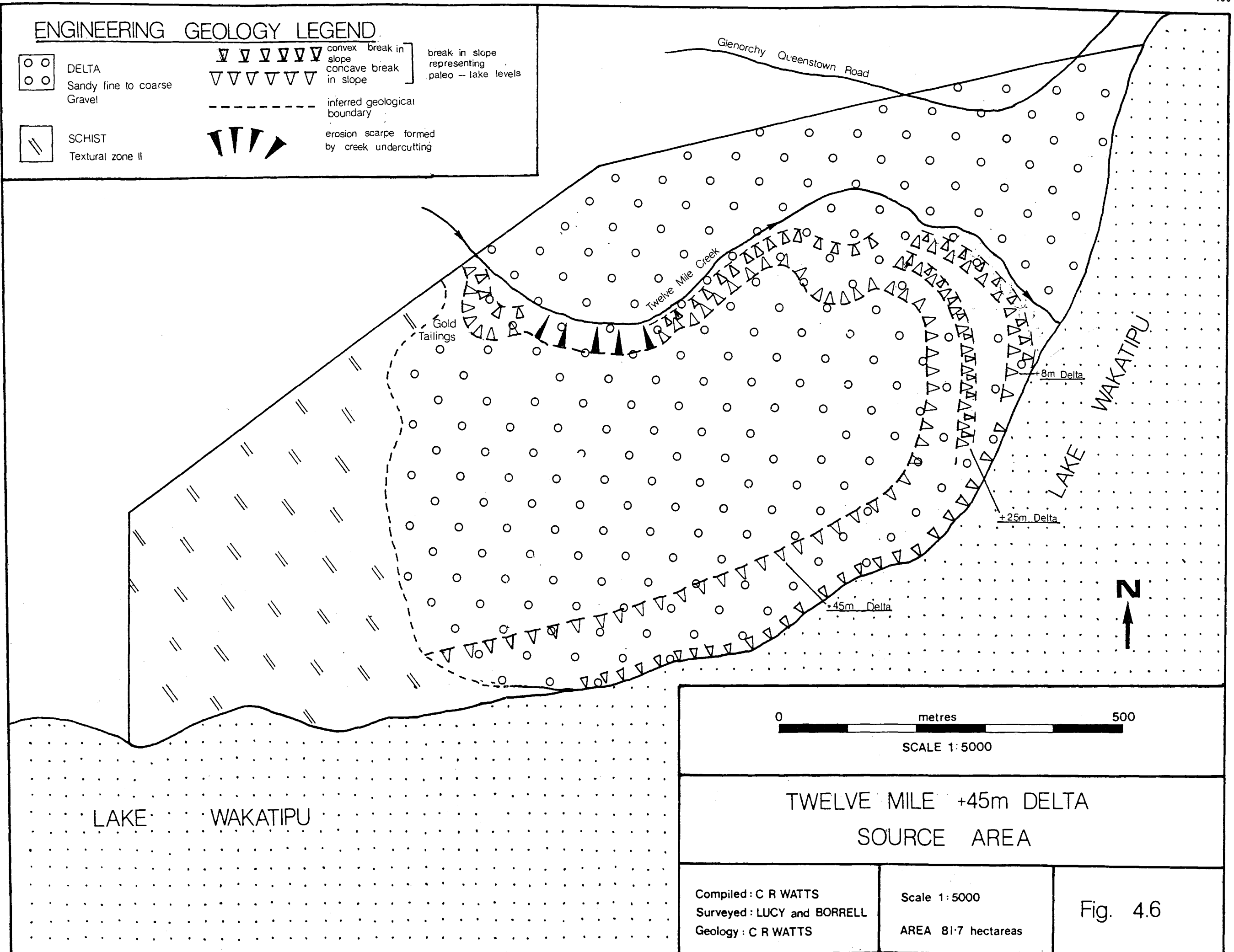


Fig. 4.6



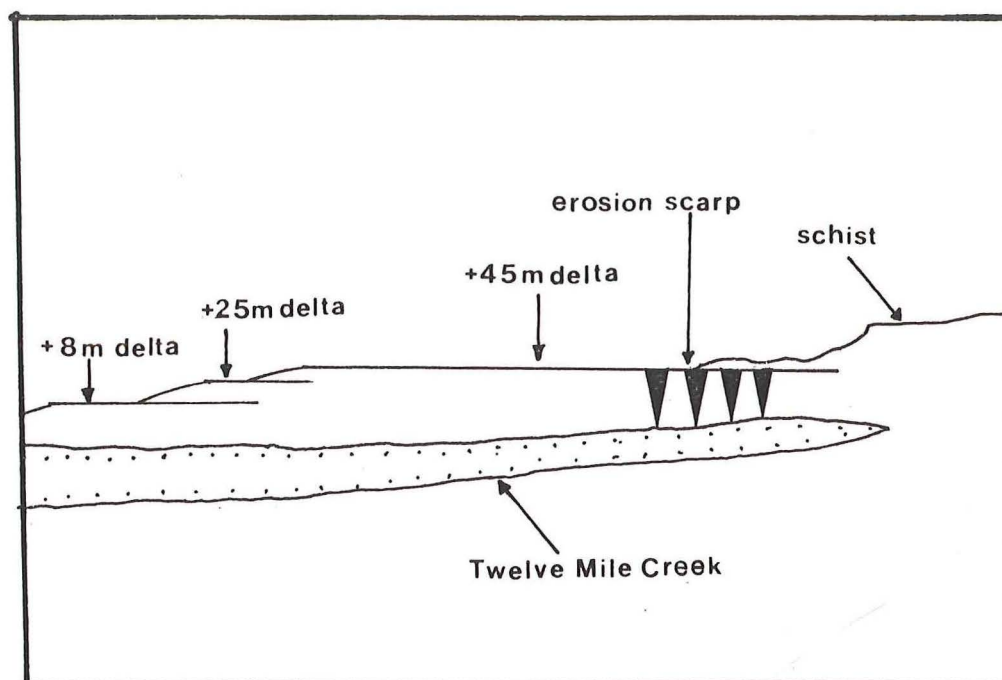


Fig. 4.7 Twelve Mile 45m delta, note deltaic material deposited at the 25m and 8m lake levels.

cave break in slope and delta-schist contact in Fig. 4.6 are approximate only. One channel sample of the delta aggregate was collected from the base of the scarp identified on Fig. 4.6. The sample was considered to be representative of aggregate within the scarp exposure.

#### 4.4.4 Geology

The deltaic aggregate consists of sandy fine to coarse gravel which contains schist, quartz and greywacke (5%). Particle shape of the aggregate is subangular to subrounded, with approximately 20-30% of the clasts demonstrating discoidal or elongate shape. An erosion scarp demonstrates that the thickness of the delta material is at least 20m. Exposures on the shore of Lake Wakatipu show delta material overlying schist.

The delta material was deposited when Lake Wakatipu was 45m above its present level (Fig. 4.6 and 4.7). Deltaic material deposited at two lower lake levels can also be recognised (Fig. 4.6 and 4.7), these deposits were deposited when the lake was approximately 25m and 8m above the present lake level. A field description of the delta aggregate is as follows:

##### SANDY GRAVEL

Light grey, unweathered, massive bedded, SANDY fine to medium GRAVEL with rare cobbles (GP/GW);

-loose to compact; dry; well to poorly graded; bedded, sub-horizontal to gently inclined, thin to thick; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (5%); sand, fine to coarse; occasional sand lenses and gravel lenses.

The deltaic material was considered as a possible aggregate source because:-

(a) The aggregate has suitable grain size for the production of roading aggregate;

(b) The existing Twelve Mile and Farry quarries use aggregate of similar engineering geological description and depositional environment to the delta aggregate, and produce roading aggregate close to the NRB M/4 specification (crushing resistance values of 110-140kN reported); and

(c) Sufficient quantity of deltaic aggregate is estimated to be present within the deposit to warrant further investigation. A conservative estimate of the insitu aggregate present within the deposit is  $300000\text{m}^3$ , and is based on the following calculation:-

A 20m scarp and exposures indicate that the delta deposit is at least 20m in thickness, over an area of 200m x 200m. Therefore, the estimated insitu volume of the deltaic deposit is  $400000\text{m}^3$ .

#### 4.4.5 Mining and Prospecting Licence Application

The proposed site is Crown land, and before the right to prospect or mine is granted a Prospecting or Mining Licence Application must be filed with the secretary of Energy. A Mining licence application for the proposed site was not granted.

The Council was requested to apply for a Prospecting Licence over the same area so that the nature and extent of the resource can be established. Council was required to supply an environmental assessment questionnaire with the Prospect Licence Application. The author, on behalf of Duffill Watts and King, compiled the Environmental Assessment Ques-

tionnaire for the Prospecting Licence Application (The Environment Assessment Questionnaire is provided in Appendix 8) At the completion of this thesis study the Queenstown-Lakes District Council prospecting licence lay in second priority, and no further site investigations could be undertaken until the first licence had expired, surrendered or withdrawn.

#### 4.5 ALTERNATIVE TWELVE MILE DELTA SOURCE AREA

##### 4.5.1 General

The right to prospect or mine the Twelve Mile +45m Delta source area was not granted (discussed in section 4.4), and this combined with the limited life of approximately two years for the Twelve Mile quarry (pers comm L Matchett County Clerk), means that supplies of basecourse roading aggregate in the Twelve Mile district would soon be depleted. The expected shortage of aggregate in the Twelve Mile area was a concern to Mr Sleath (County Engineer) and Mr Matchett (County Clerk). Mr Sleath suggested an alternative source area, and instructed the author to carry out investigations. The suggested site was on the uphill side of the Queenstown-Glenorchy Road and on the true right bank of the Twelve Mile Creek (Fig. 4.1).

##### 4.5.2 Site Description and Investigation

The source area slopes at  $5-10^0$  towards the road. Exposure of the aggregate occurs in the road cutting and where the Twelve Mile Creek has incised through the aggregate.

The site investigations were restricted to a walk over

survey and logging of exposures.

#### 4.5.3 Geology

The aggregate present at the proposed site is a deltaic aggregate consisting of sandy gravel which contains schist, quartz and greywacke (5%).

Exposures indicate that deltaic aggregate is 5m thick and occurs over an area of at least 100m x 100m, therefore an estimated 50000m<sup>3</sup> of insitu aggregate is present within the resource. The aggregate has a similar description and depositional environment to aggregate exposed at the Twelve Mile aggregate. Therefore, it is expected that the aggregate will produce roading aggregate of similar quality to the present Twelve Mile roading aggregate. A description of the aggregate is as follows:

##### SANDY GRAVEL

Light grey, unweathered, massive bedded, SANDY fine to medium GRAVEL with rare cobbles (GP/GW);

-loose to compact; dry; well to poorly graded; bedded, sub-horizontal to gently inclined, thin to thick; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (5%); sand, fine to coarse; occasional sand lenses and gravel lenses.

#### 4.5.4 Further Investigations

Further investigations would be required to provide a better estimate of the quality and quantity of the aggregate present in the source areas. However, the land is owned by the Crown and a mining licence would have to be acquired before quarrying could start. Therefore, consideration should be given to the cost of acquiring a mining licence for a lim-

ited amount of aggregate (70000m<sup>3</sup> loose measurement).

#### 4.6 ARTHURS POINT OUTWASH SURFACE

##### 4.6.1 General

When it was established that the rights to quarry the Twelve Mile +45m delta source area were not granted, Duffill Watts and King instructed the author to carry out field work to locate additional source areas capable of producing NRB M/4 quality roading aggregate within the geographical limits of the Lumberbox and Twelve Mile quarries. Field work identified the Arthurs Point outwash surface as a potential aggregate source area (Fig. 4.1).

##### 4.6.2 Site Description and Investigations

The Arthurs Point outwash source area is located north Malaghans Road (Fig. 4.1). The site demonstrates flat lying terraces extending from the Arthurs Point recessional moraine (Fig. 2.6). The site has been agriculturally developed, and hence exposures are limited and of poor quality. Field work on the site included a walk over survey of the area and logging of two exposures.

##### 4.6.3 Geology

The source area is located within the Arthurs Point outwash surface. The outwash aggregate consists of gravel with some sand, which contains schist, quartz and greywacke (20-30%). Exposures of the outwash terraces suggest that the outwash material is at least 4m in thickness, and occurs over an area of 200m x 150m, therefore a minimum estimated insitu

quantity of the resources is 100000m<sup>3</sup>.

The Arthurs Point outwash material has been identified as a potential source area because of the grain size and greywacke content. The grain size of the outwash gravel is envisaged to contain sufficient coarser grained aggregate (ie. >20mm) to produce roading aggregate that will meet the M/4 AP40 grading requirement. The greywacke content should enable the aggregate to produce a crushing resistance of greater than 130kN. Outwash is typically deposited by swiftly flowing streams, therefore the aggregate is expected to have most of the glacial silts "washed" out, which may allow the sand equivalent values to be of M/4 quality. The suggested quality and quantity of the outwash aggregate is tentative and based only on geomorphology and two outcrops.

During the waning stages of the Otiran glaciation, the Shotover River may have been diverted by the receding glacier to flow along the depression at the base of Coronet Peak (Bell 1982). The timing and extent of deposition is unknown, but the Shotover River may have reworked the outwash material, and deposited schist-derived aggregate at the site.

A field description of aggregate from the source area is as follows:

Light grey, unweathered, massive, Sandy fine to coarse Gravel with some sand and cobbles (GP/GW).

-well to poorly sorted; gravel, schist, TZ II, III, IV, greywacke (20-30%) and quartz, subangular to rounded; sand fine to coarse.

#### 4.6.4 Further Investigations.

Additional site investigation would be required to establish the quality and quantity of the aggregate present

in the outwash deposit. Further site investigations would include mapping at a scale of 1:1000-1:2000, logging of test pits, and the collection of samples.

#### 4.7 QUEENSTOWN-GLENORCHY, KINLOCK-GLENORCHY and GREENSTONE STATION ROADS.

##### 4.7.1 General.

The author, on behalf of Duffill Watts and King was instructed by Council to locate possible aggregate source areas along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads. The aim of the survey was to locate potential aggregate source areas that may be capable of producing NRB M/4 quality roading aggregate. Roding aggregate of sub-M/4 quality would also be a valuable resource, as roads in this area are unsealed. The source areas identified along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads are discussed in this section. The discussion includes an engineering geological description and an estimation of quantity of aggregate within each resource.

##### 4.7.2 Investigations

Numerous aggregate source areas are available along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads, however only a selection of the higher quality and more accessible aggregate source areas are provided below.

At this preliminary stage of investigation, permission to sample the source areas had not been sought, therefore sampling was not carried out. Estimations of quantity of



insitu aggregate within the resource are inferred from exposures and geomorphology, and therefore provide only an indication of the quantity. However, the purpose of providing an estimation of quantity of the resource is to aid the Council in its decision as to which source area warrants further investigation.

#### 4.7.3 Engineering Geology of Source Areas

Seven potential aggregate source areas have been identified, and all are +45m or +25m lake delta deposits. The deposits are associated with all of the larger creeks and rivers located along the length of the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads (Fig. 4.8). The delta deposits are generally a massive to laminated and consists of, sandy gravel mixture. The particle shape of the deltaic aggregate is typically subrounded to subangular, with approximately 10-30% demonstrating discoidal or elongate shape. A brief description, and an estimation of quantity and particle shape of the source areas is provided in Table 4.2.

A general field description of the deltaic deposits is as follows:

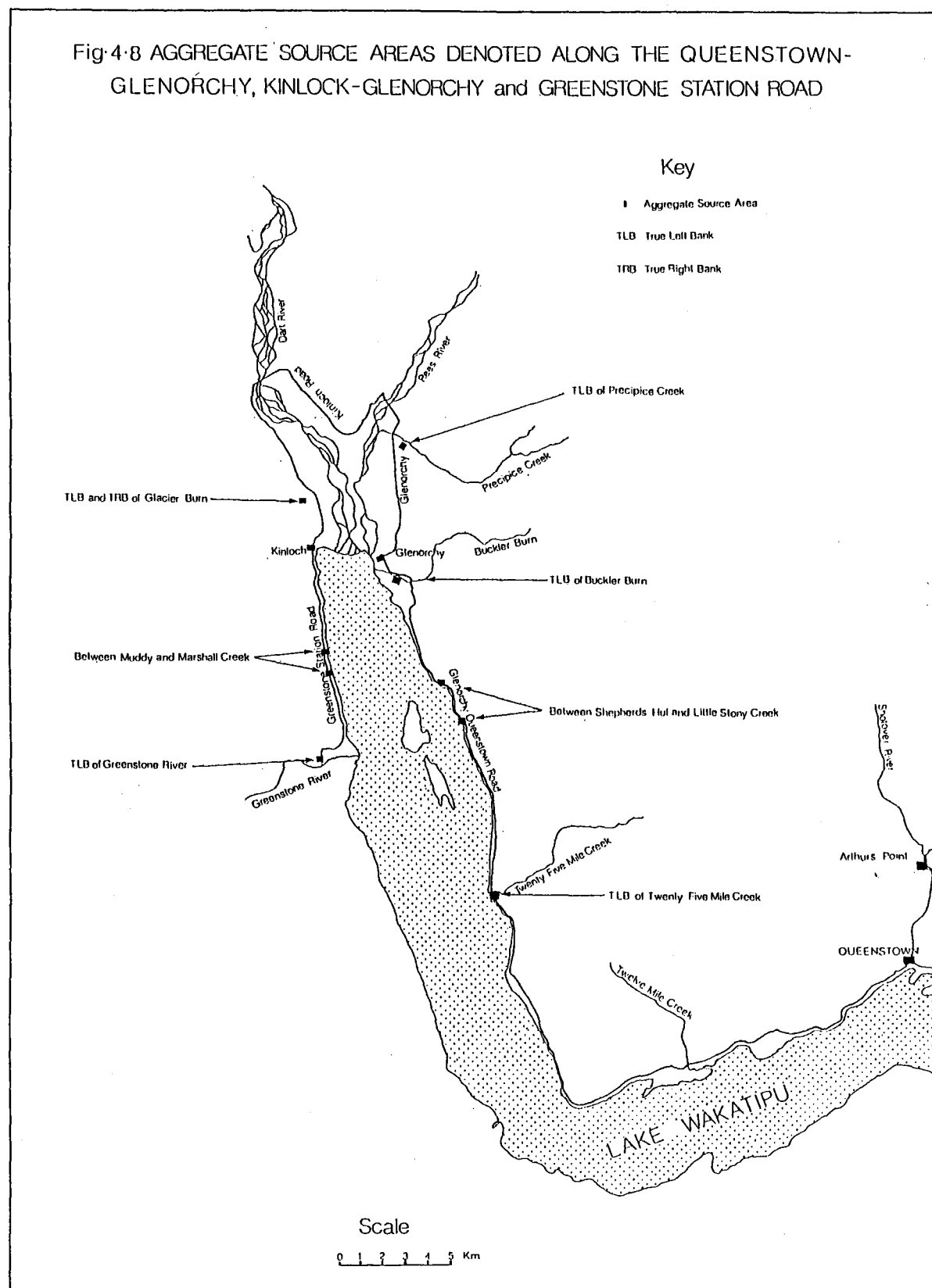
##### SANDY GRAVEL

Light grey, unweathered, massive to bedded, SANDY fine to coarse GRAVEL with rare cobbles (GP/GW);

-loose to compact ; dry; well to poorly graded; bedded, sub-horizontal to moderately inclined, thin to thick; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke; sand, fine to coarse; occasional sand lenses and gravel lenses.

The only difference between the descriptions of the delta source areas is the greywacke and textural zone II, III

Fig. 4.8 AGGREGATE SOURCE AREAS DENOTED ALONG THE QUEENSTOWN-  
GLENORCHY, KINLOCK-GLENORCHY and GREENSTONE STATION ROAD



Source Areas Along the Queenstown - Glenorchy, Kinloch - Glenorchy and Greenstone Station Roads.			
Location	Description	Estimated quantity	Particle shape
TLB of the Twenty Five Mile	Sandy Gravel TZ II, III, IV, quartz	>100 000m <sup>3</sup>	Subrounded- subangular 20% discoidal
Between Shetlands Hut Creek and Little Stoney Creek	Sandy Gravel TZ III, IV, quartz	>200 000m <sup>3</sup>	Subrounded- subangular 20% discoidal
TLB of Buckler Burn	Sandy Gravel TZ III, IV, quartz	>200 000m <sup>3</sup>	Subrounded- subangular 20% discoidal
TLB of Precipice Creek	Sandy Gravel TZ III, IV, quartz	>50 000m <sup>3</sup>	Subrounded- subangular 10% discoidal
TLB and TRB of Glacier Burn	Sandy Gravel TZ II, III, quartz, grey- wacke (20-30%)	>50 000m <sup>3</sup>	rounded- subangular 30% discoidal
Between Muddy Creek and Marshall Creek	Sandy Gravel TZ II, III, quartz, grey- wacke (40-50%)	>50 000m <sup>3</sup>	rounded- subangular 30% discoidal
TLB of Green- stone River	Sandy Gravel TZ II, III, quartz, grey- wacke (50-60%)	>100 000m <sup>3</sup>	rounded- subangular 30% discoidal

Table 4.2 Data summary of source areas along Queenstown - Glenorchy,  
Kinloch - Glenorchy and Greenstone Station Roads.

and IV content.

The greywacke content of the aggregates increases from source areas on the east side of Lake Wakatipu to source areas on the west side. This is attributable to the Caples Group rocks (greywacke) outcropping on the western side of the lake (Fig. 1.3). During the last glaciation the greywacke-rich ice lobes entering the Wakatipu Glacier were restricted to the western side of the valley, making glacial transport of the greywacke rich material to the east side of the lake difficult to envisage. It would seem likely that the greywacke rich glacial material presumably lateral and medial moraine, was restricted to the western side of the lake at least until about the Twelve Mile area.

During the deposition of the deltaic deposits, the aggregate has been "washed", therefore it is envisaged that these deltaic aggregates will be capable of producing sand equivalent values of NRB M/4 standard. The deltaic deposits with greater than 10% greywacke are likely to be capable of meeting the M/4 crushing resistance requirement.

#### 4.7.4 Source Areas Descriptions

##### (i) True left bank of the Twenty Five Mile.

The source area is located on the true left bank of the Twenty Five Mile Creek, and on the uphill side of the Queenstown-Glenorchy Road (Fig. 4.8). This deltaic deposit is also exposed on the true right bank in the Twenty Five Mile quarry (discussed in section 3.8). The source area is inferred to have similar aggregate properties to the Twenty Five Mile quarry.

The estimated quantity of the resource is  $100000\text{m}^3$ , which assumes that the inferred thickness of the delta is at

least 5m over an area of 200m x 100m.

(ii) Between Shetlands Hut Creek and Little Stoney Creek.

The source area is located between Shetlands Hut Creek and Little Stoney Creek, and on the uphill side of the Queenstown-Glenorchy Road (Fig. 4.8). The minimum estimated quantity of the resource is  $200000\text{m}^3$ , which is based on a delta thickness of at least 5m over an area of 400m x 100m.

(iii) True Left Bank of Buckler Burn.

The source area is located on the true left bank of the Buckler Burn, and on the uphill side of the Queenstown-Glenorchy Road (Fig. 4.8). Queenstown-Lakes District Council presently has a gravel licence to remove aggregate from the Buckler Burn (discussed in section 3.10.4). Aggregate from the source area is predicted to have similar geotechnical properties to the gravel licence aggregate.

The minimum estimated quantity of the resource is  $200000\text{m}^3$ , which is based on a delta thickness of at least 10m, over an area of 200m x 100m.

(iv) True Left Bank of the Precipice Creek.

The source area is located on the true left bank of the Precipice Creek and on the uphill side of the Queenstown-Glenorchy Road (Fig. 4.8). Queenstown-Lakes District Council presently has a gravel licence to remove aggregate from the Precipice Creek (discussed in section 3.10.9). Aggregate from the source area is envisaged to have similar geotechnical properties to the gravel licence aggregate.

The minimum estimated quantity of the resource is

50000m<sup>3</sup>, which is based on a delta thickness of at least 5m over an area of 200m x 50m.

(v) True Left Bank and True Right Bank of the Glacier Burn.

The source area is located on the true left bank and true right bank of the Glacier Burn and on the uphill side of the Kinlock-Glenorchy Road (Fig. 4.8). Queenstown-Lakes District Council presently has a gravel licence to remove aggregate from the Glacier Burn. Aggregate from the source area is envisaged to have similar geotechnical properties to the gravel licence aggregate.

The minimum estimated quantity of the resource is 50000m<sup>3</sup>, which is based on a delta thickness of at least 5m over an area of 200m x 50m. The greywacke content of the Glacier Burn deltaic aggregate is envisaged to produce crushing resistance values of NRB M/4 standard.

(vi) Between Muddy Creek and Marshall Creek.

The source area is located between Muddy Creek and Marshall Creek on the uphill side of the Greenstone Station Road (Fig. 4.8).

The minimum estimated quantity of the resource is >50000m<sup>3</sup>, which is based on a delta thickness of at least 5m over an area of 200m x 50m. The greywacke content of the deltaic aggregate is thought to produce crushing resistance values of NRB M/4 standard.

(vii) True Left Bank of the Greenstone River.

The source area is located on the true left bank of the Greenstone River and on the uphill side of the Greenstone

Station Road (Fig. 4.1).

The minimum estimated quantity of the resource is  $100000\text{m}^3$ , which is based on a delta thickness of at least 10m over an area of 150m x 70m. The greywacke content of the deltaic aggregate is expected to produce crushing resistance values of NRB M/4 standard.

#### 4.7.5 Further Investigations

To further establish the quality and quantity of the aggregate source areas, additional site investigations are required. Suggested further investigations are engineering geological mapping at the scale of 1:1000 - 1:2000, logging and excavation of test pits, and the collection of test samples.

### 4.8 PROPOSED FULTON HOGAN QUARRY

#### 4.8.1 General

Watson Buckham and Co. (Solicitors and Barristers), on behalf of D. Jardine, advised the Queenstown-Lakes District Council of a proposed aggregate quarry on their clients property (Fig. 4.1). Council and other interested parties were given an invitation to contract for the quarry.

Registered surveyors, Clark Fortune McDonald and Associates, completed site investigations for D. Jardine at the proposed aggregate quarry. The surveyors prepared a plan and cross-section of the proposed aggregate quarry and calculated that there was a gross insitu volume available from the quarry area of  $427000\text{m}^3$ . This volume is based on excavations of the aggregate quarry down to the level of the adjoining

gully floors. Clark Fortune McDonald and Associates comment that no tests had been carried out to establish the quality of the aggregate, and that quality determination of the aggregate would be the responsibility of the future quarry operator.

The author, on behalf of Duffill Watts and King was instructed by Council to establish the quantity and quality of the aggregate for the purpose of producing roading aggregate.

#### 4.8.2 Proposed Quarry Site Description

The site of the proposed aggregate quarry is identified on Fig. 4.2 as "Proposed Fulton Hogan Aggregate Quarry". The site of the aggregate quarry slopes towards the Lake at approximately  $5^{\circ}$ . The western edge of the proposed site is marked by an increase in slope angle formed by the episodic lake lowering.

The northern and southern boundaries of the quarry consist of two creeks which have incised approximately 20m into the fan delta complex (Fig. 4.9). The approximate dimensions of the proposed aggregate quarry are a rectangular prism with the measurements of 180m long by 110m wide by 20m deep, (ie. approximately 400000m<sup>3</sup>).

#### 4.8.3 Geology

##### (i) Quantity

Along the northern boundary of the proposed aggregate quarry, approximately 60% exposure of the geology occurs in the gully scarps (Fig. 4.9). In the gully forming the southern boundary, approximately 20% exposure of the geology is present.



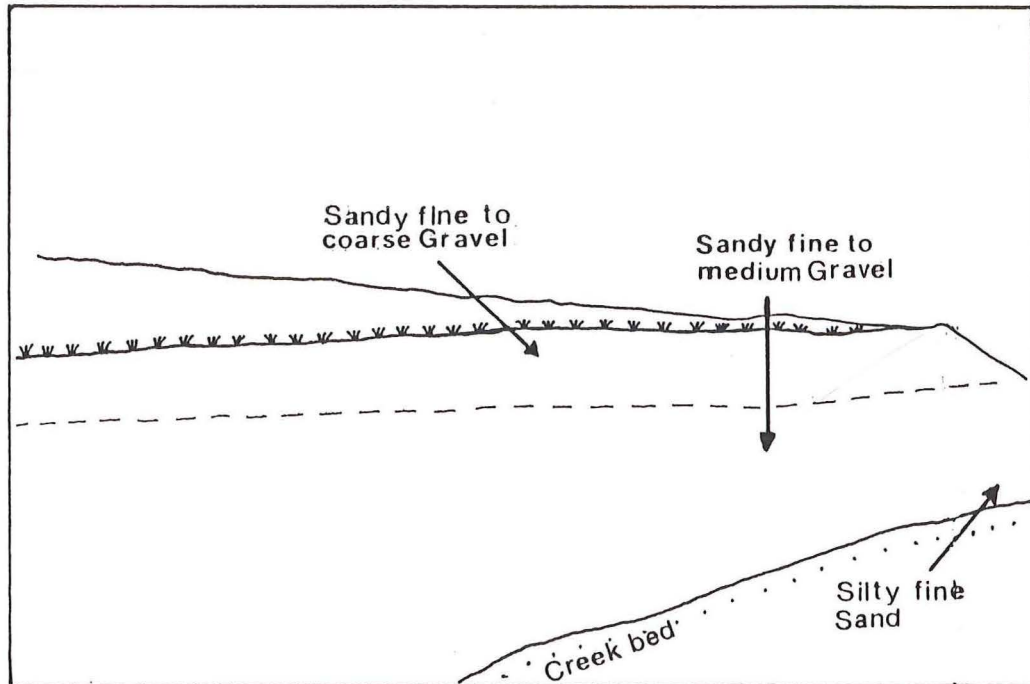


Fig. 4.9 Proposed Fulton Hogan Ltd. quarry, note the reduction in grain size.

The proposed aggregate quarry is located within the field area of Fig. 4.2 and has been mapped as fan-delta complex. The fan-delta complex material of the field area was not considered as a potential aggregate source area as the aggregate was too finely grained for production of M/4 AP40 roading aggregate.

The fan-delta complex material of the proposed aggregate quarry demonstrates an upward coarsening in grain size. Exposures in the distal location (at the base of the gully at the Lake's edge) of the fan-delta complex consist of a sand/silt with some gravel. The grain size gradually increases to sandy fine to coarse gravel at the more proximal location of the complex, (ie. most upslope of the quarry site) (Fig. 4.9). Coarser grained sediments of the fan-delta complex are restricted to the top 3-5m of the exposure.

To produce crushed roading aggregate (ie M/4 AP40) the parent aggregate must contain a proportion of coarser gravel fraction grained (ie. >20mm). Therefore, only the top 3-5m of aggregate available from the proposed quarry would be suitable for M/4 AP40 production. Based on this assumption the maximum amount of usable insitu aggregate would be approximately 100000m<sup>3</sup>.

If production methods of roading aggregate similar to the Lumberbox were used and the -19mm were scalped out, an estimated 50% would be scalped out. Assuming that the insitu dry density of the aggregate was 2.1 t/m<sup>3</sup> and the loose density of the aggregate was 1.5 t/m<sup>3</sup>, the proposed aggregate quarry would supply a maximum amount of 70000m<sup>3</sup> of aggregate (loose measurement).

(ii) Quality

The greywacke content of the fan-delta complex is suggested to produce a crushing resistance values of M/4 standard, however because the fan-delta complex is derived from glacial material the sand equivalent values of the deposit may be sub-M/4 standard.

#### 4.8.4 Proposed Quarry

An estimation of the present annual roading aggregate requirements of the Queenstown-Lakes District Council is 30000m<sup>3</sup> loose measurement (pers comm, R. Duff, County Engineer). The estimated maximum quantity of aggregate available from the proposed quarry is therefore only two years supply. Based on this information, the cost of further site investigations, and Council completing site investigations for an aggregate quarry in the immediate area, Council declined the invitation to tender for the proposed aggregate quarry.

#### 4.9 SYNTHESIS.

The aggregate survey identified four potential aggregate source areas;

(a) Kame terraces on the lower western slopes of The Remarkables;

(b) Twelve Mile +45m delta;

(c) Alternative Twelve Mile delta; and

(d) Arthurs Point outwash surface.

The Queenstown-Lakes District Council initiated further investigations of the kame terrace and Twelve Mile source

areas.

A section of The Remarkables Station was mapped, and during the field work five aggregate sources were identified:-

- (a) Otiran alluvial fans;
- (b) Kame terraces;
- (c) Deltas;
- (d) Fan-delta complexes; and
- (e) Alluvial fan.

Of these aggregate sources, kame terraces and alluvial fans were expected to produce the highest quality roading aggregate. Kame terraces contain a higher percentage of greywacke, and therefore were suggested to Council as potential source area.

Investigations of the kame terrace source area included engineering geological mapping, excavation and logging of thirteen test pits, a crushing trial, and the collection of test samples. Within the Kame terrace source area till, kame terraces, deltas and alluvial fan units were identified. Kame terrace and alluvial fan aggregates were predicted to be capable of producing basecourse roading aggregate. The kame terrace and alluvial fan aggregate typically consists of sandy fine to coarse gravel with some silt which contains schist and greywacke (20%). The kame terrace source area is estimated to contain at least 900000m<sup>3</sup> of insitu aggregate, which is expected to meet the Queenstown-Lakes District Council total roading aggregate requirements (at present production rates) for Twenty years.

Based on information supplied by the author concerning quality and quantity of aggregate available from the kame terrace source area, the Queenstown-Lakes District Council

decided to develop an aggregate quarry within the source area. Planning approval for an aggregate quarry in the kame terrace source area was granted, subject to ten conditions. A contract to construct the access track and laybay for the quarry has been completed. The quarrying and crushing contract to produce subbase and basecourse was not let at the completion of the thesis.

Investigations of the Twelve Mile source area included engineering geological mapping and the collection of one channel sample. The Twelve Mile deltaic aggregate consists of sandy fine to coarse gravel which contains schist and greywacke (<10%), and is predicted to be capable of producing similar quality roading aggregate to the Twelve Mile and Farry quarries. An estimated insitu volume of the deltaic resource is 400000m<sup>3</sup>.

The source area is located on Crown land, and before further investigations could be carried out, Mining or Prospecting licence is required. A Mining and Prospecting licence within the source area of the Twelve Mile +45m delta was not granted, and no further investigations could take place.

An alternative source area within the Twelve Mile district was proposed by Mr Matchett, and the author was instructed to investigate the deposit. Investigations identified a deltaic deposit of similar engineering geological description to the Twelve Mile and Farry quarries. However, the quantity of aggregate within the deposit is limiting and the cost of a mining licence and further investigations may not be warranted.

Field work for the aggregate survey identified the Arthurs Point outwash surface, the deposit consists of gravel

with some sand, which contains schist and greywacke (20-30%). The depositional environment and greywacke content of the outwash deposit suggests that roading aggregate produced from the deposit will meet the M/4 sand equivalent and crushing resistance requirements.

Seven source areas have been identified along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads. All of the source areas are located within +45m or +25m lake delta deposits. The source areas are expected to be capable of producing sand equivalent values of NRB M/4 standard. The three source areas that contain greywacke are suggested to be capable of producing roading aggregate with crushing resistance values of NRB M/4 quality, however these deposits are located 80km from Queenstown.

Council was invited to tender for an aggregate quarry within the Jardine's property. The aggregate source was located within the field area of Fig. 4.2 and was mapped as a fan-delta complex. The fan-delta complex demonstrates a decrease in grain size, from a proximal to a distal location within the complex. Only the upper 3-5m of the fan delta complex contains coarse grained aggregate suitable for the production or basecourse. Therefore, reducing the useable quantity of aggregate from the site to an estimated 100000m<sup>3</sup> (insitu), based on this information the Queenstown-Lakes District Council declined the invitation to tender for the proposed quarry.

## CHAPTER FIVE

## GEOTECHNICAL TESTING

## 5.1 INTRODUCTION

5.1.1 Geotechnical Tests

The procedure and results of the geotechnical tests are discussed in this chapter. The sampled aggregates are compared with the NRB M/4 1985 specification and other roading aggregates from the Wakatipu Basin.

Council has initiated further investigations of only two source areas, the Twelve Mile +45m delta source area and the kame terrace source area, which is the site of the proposed Queenstown-Lakes District Council quarry. Therefore, only these sites have been sampled and tested. Ten geotechnical tests have been carried out on samples from these source areas, the tests are as follows:

- (a) Grain Size Analysis, (NZS 4402 Test 9(a) and 9(b));
- (b) Proportion of Broken Rock, (NRB M/4 1985);
- (c) Sand Equivalent, (NZS 4402 Test 7 (1980));
- (d) Weathering Resistance, (NZS 3111 Test 15 (1980));
- (e) Crushing Resistance, (NZS 3111 Test 14 (1980));
- (f) Los Angeles Abrasion, (Ministry of Works and Development Central Laboratories DES C 114-69);
- (g) Lithological Analysis;
- (h) Atterberg Limits, (NZS 4402 Test 1 and 2 (1980));
- (i) Clay Index Test, AEL Report, R. High (1983); and
- (j) X-ray Diffraction.

Tests (a) to (e) form the required tests of the NRB M/4 specification, and have been used to establish whether the

sampled aggregate meets the NRB M/4 standard.

The remaining tests were used to further assess the quality of the aggregates. Lithological analysis was carried out to provide an accurate assessment of the percentage of greywacke in each of the coarse aggregate fractions. Clay index, Atterberg limits and X-ray diffraction tests were carried out on the fine fraction of the aggregates to provide a better understanding of the fine fraction and to supplement the information obtained by the Sand Equivalent tests. The Los Angeles abrasion tests were completed to supplement information obtained from the crushing resistance tests about the strength and hardness of the coarse aggregate fraction.

#### 5.1.2 Sampling

##### (i) Kame Terrace Source Area.

From the kame terrace source area nineteen 30-40kg channel samples were collected from test pits. The location and depth at which the channel samples were collected is represented on Fig. 4.5. During collection of the channel samples boulders and large cobbles (>200mm) were omitted to limit the samples to a practical size. However, this is not thought to greatly affect the samples, as the amount of sample omitted is approximately <5% of the total sample.

Test Pit 13 (ie. alluvial fan) was excavated to provide a 40m<sup>3</sup> crushing trial. The crushing trial was excavated from alluvial fan aggregate, because the loader and truck that were used to load and transport the aggregate, were only able to obtain access to the alluvial material. A crushing trial was not carried out on kame terrace aggregate. The crushing trial was loaded and transported to the Lumberbox quarry, and crushed with a Kue-Ken Jaw Crusher. Two methods of processing



the aggregate were used:

(a) oversize (>300mm) aggregate scalped out and remainder crushed (all-in crushed);

(b) -19mm and oversize (>300mm) aggregate scalped and the remainder crushed (scalped/crushed).

The two crushed roading aggregates were stockpiled. Three 30-40kg samples of the all-in crushed aggregate (sample No. 15C, 16C, and 17C) and three 30-40kg samples of the scalped/crushed aggregate (sample No. 12SC, 13SC, and 14SC) were collected in accordance with NZS 3111 1980 Test 5 (Methods for Sampling Aggregate). During the crushing trial of the scalped/crushed aggregate, approximately 50% of the original aggregate was scalped out, the majority (ie. >95%) of the scalpings being -19mm size.

All except three samples were tested at the University of Canterbury in the Engineering Geology Laboratory and/or the Civil Engineering Department. The three samples not tested at the University were 6A, 7A and 13SC (Table 5.1). Samples 6A and 7A were uncrushed channel samples, which were tested for grading, crushing resistance and sand equivalence by the Ministry of Works and Development in Alexandra. A grading was also carried out on sample 13SC by the Ministry of Works and Development in Alexandra. The deposits from which the samples were collected and the tests carried out on the samples are represented on Table 5.1 and 5.2.

(ii) Twelve Mile +45m Lake Delta Source Area.

One channel sample 30-40kg was collected from the Twelve Mile +45m Lake Delta source area (Fig. 5.1) (sample No. 12.1), in anticipation of the Queenstown-Lakes District Council being granted a prospecting licence. However, the

	Geotechnical Test	Particle Size Distribution		Crushing Resistance	Sand Equivalent	Clay Index	Plasticity Index	Lithological Analysis
		9(b)dry	9(a)wet					
Kame terrace	2A	x						x
	2B	x						x
	3A	x						x
	3B	x						x
	4A	x						x
	5A	x						x
	6A		0	0	0			
	6B		x			x	x	x
	7B	x						x
	8B	x						x
Kame terrace source area samples	1A	x						x
	1B	x						x
	7A		0	0	0			
Fan alluvium	6A	x						x
	9A	x						x
	9B	x						x
	10A	x						x
Till	11A	x						x
Twelve Mile 45m delta source area	12.1		x	x	x	x	x	x

O: samples tested by Ministry of Works and Development, Alexandria.

Table 5-1 Geotechnical tests carried out on uncrushed samples from the kame terrace and Twelve Mile +45m delta source areas.

Geotechnical Tests	Particle Size Distribution	Weathering Resistance	Crushing Resistance	Sand Equivalent	Los Angeles Abrasion	Clay Index	Plasticity Index	Lithological Analysis	X-ray Diffraction
13SC	9(b)dry 9(a)wet o								
12SC	x	x	x		x			x	
14SC	x			x		x	x	x	x
16C	x							x	
15C	x	x	x	x	x			x	
17C	x			x		x	x	x	x

o: samples tested by Ministry of Works and Development, Alexandra.

Table 5.2 Geotechnical tests carried out on crushed fan alluvium samples from the kame terrace source area.



Fig. 5.1 Channel sample from Twelve Mile +45m delta source area.

prospecting licence was not granted and no further sampling was carried out (discussed further in section 4.4.5). The single channel sample was collected from the base of the scarp identified on Fig. 4.6. The sample was thought to have been representative of the aggregate within the scarp exposure.

## 5.2 PARTICLE SIZE DISTRIBUTIONS

### 5.2.1 Analysis Methods

Particle Size Analysis was completed in accordance with NZS 4402 Test 9(a), 9(b), and 9(c) (1980). The NRB M/4 specification requires the particle size distribution of the base-course to lie within specified grading limits. The National Roads Board M/4 AP40 AP20 grading specifications are provided in Table 5.3 and Fig. 5.2.

The purpose of the M/4 grading envelope is to provide a dense poorly graded aggregate which will resist deformation in the pavement structure. Valuable information about the suitability of a roading aggregate may be obtained from the density of a pavement. In New Zealand it has become common practice to express the density of a roading aggregate in terms of Talbott's Equation (Bartley 1986), which is as follows:

$$P_d = 100(d/D)^n$$

where;

$P_d$  - is the amount of material smaller than  $d$  expressed as a percentage of the total mass of material in the size

Test sieve. Aperture	Percentage passing	
	AP40	AP20
37.5mm	100	
19.0mm	66 - 81	100
9.5mm	43 - 57	55 - 75
4.75mm	28 - 43	33 - 55
2.36mm	19 - 33	22 - 42
1.18mm	12 - 25	14 - 31
600um	7 - 19	8 - 23
300um	3 - 14	5 - 16
150um	10 max	12 max
75um	7 max	8 max

Table 5.3 Grading envelope for M/4 AP40 and M/4 AP20.

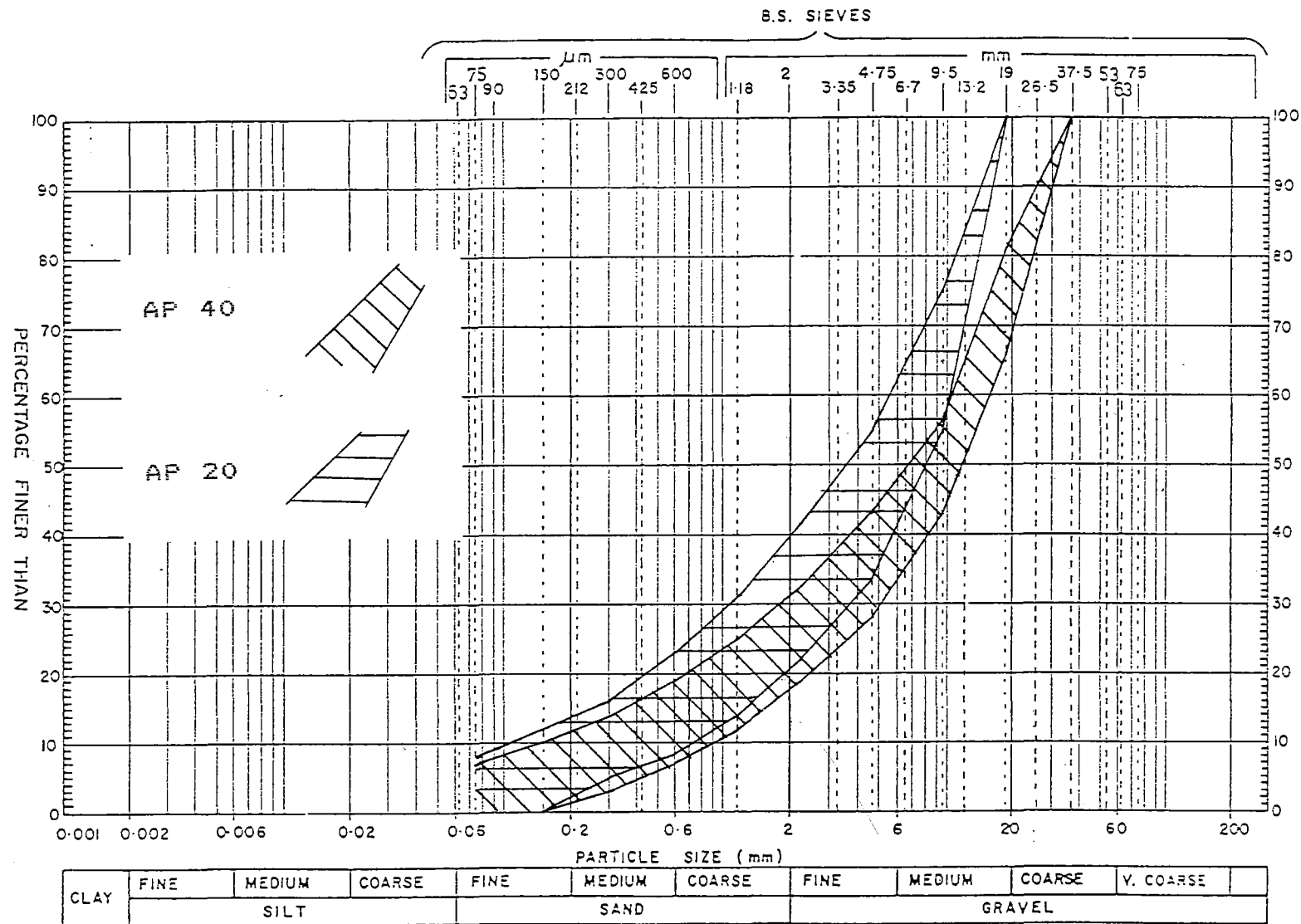


Figure 5.2 NRBM/4:1985 grading envelopes

range being described,

$d$  - is any particle size smaller than the top size  $D$  of the size range being described and

$n$  - is Talbot's exponent or " $n$ " value. (Tonkin and Taylor 1972)

Densely graded aggregates have " $n$ " values of less than 0.45 and coarsely graded aggregates have  $n$  values in excess of 0.55. The NRB M/4 grading envelope lies between the values of 0.40 and 0.60.

Krebs and Walker (1971) suggest the following descriptions based on " $n$ " values.

(a)  $n > 0.60$

"An aggregate with few fines, would have grain to grain contact, variable density, be pervious, non-frost -susceptible, high stability if confined, low stability if unconfined, not be affected by adverse water condition and be very difficult to compact."

(b)  $n = 0.45 - 0.5$

"A soil aggregate mixture with sufficient fines for maximum density, would have grain to grain contact with increased resistance to deformation, increased density, be practically impervious, be frost susceptible, have high stability in confined or unconfined conditions, not be affected by adverse water content and moderately difficult to compact."

(c)  $n < 0.4$

"A soil aggregate mixture with a great amount of fines would have aggregate floating in soil, decreased density, be practically impervious, be frost susceptible, have low stability, be greatly affected by water condition, and not difficult to compact."



The n values have been calculated for the samples tested, and have been used to compare the aggregates with the Lumberbox roading aggregate and NRB M/4 grading specifications.

#### 5.2.2 Uncrushed Aggregate Particle Size Distribution Results

##### (i) Kame Terrace Source Area.

Gradings of channel samples collected from kame terrace source area test pits are included in Appendix 9 and show composite grading envelopes of kame terrace and alluvial fan material.

It is evident from the particle size distributions that the kame terrace material has a higher percentage of fines and a more variable grain size than the alluvial material. Typically, the kame terrace material ranges from silty/sandy fine to coarse gravel, to a sandy fine to coarse gravel with rare silt. The alluvial material is more consistent and typically ranges from a sandy fine to coarse gravel with some silt, to a gravel with some sand and very rare silt.

During production of roading aggregate in the Wakatipu Basin it is common practice to scalp out -19mm material before crushing. The purpose of scalping is to remove unwanted fines (<4.75mm) to enable the roading aggregate to meet the grading requirement. This method is used at the Lumberbox and Twelve Mile quarries. If a similar method was used at the proposed Queenstown-Lakes District Council quarry the grading envelope (Fig. 5.3) indicates that between 87% and 48% of the kame terrace material would be scalped out. However, the grading of sample 5A (Appendix 9) demonstrates that the sample has a higher silt and sand content than the

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

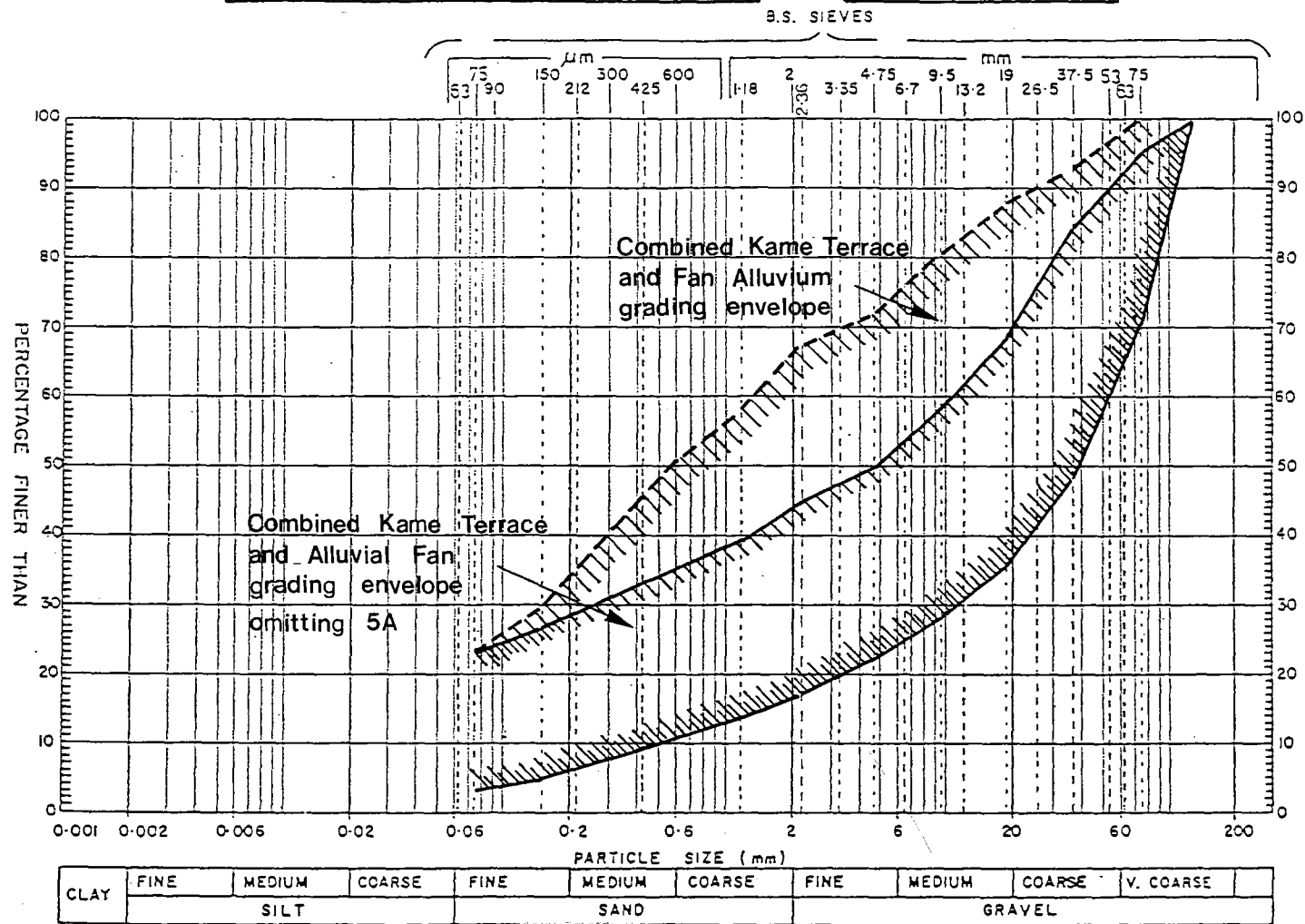


Fig. 5.3 Grading envelopes of kame terrace samples.

remaining samples, indicating that this may be an exception. Therefore, if sample 5A is omitted from the grading envelope the estimated average to be scaled out is  $59\% \pm 11\%$ .

The alluvial fan grading envelope (Fig. 5.4) infers that an average of  $44\% \pm 8\%$  of the alluvial material would be scalped out. The combined gradings envelopes (Fig. 5.5) of the kame terrace and alluvial material suggest that an average of  $62\% \pm 25\%$  of the aggregate will be scalped out, however if sample 5A is omitted the percentage to be scalped out is  $53\% \pm 16\%$ . This scalping percentage is similar to the estimated amount of scalpings produced during production at the Lumberbox quarry (pers comm L Matchett County Clerk).

Particle size distribution of till from test pit 11A (Appendix 9) demonstrates the characteristic finer grain size of the till material, with 33% of the material being silt and clay size. A description of the material is a Grav-elly Silty Sand.

#### (ii) Twelve Mile Creek Source Area.

As discussed in section 5.1.2, only one sample was collected therefore the results of tests only provide an indication of the aggregate properties.

The particle size distributions of the channel sample collected, from the delta material is presented in Fig. 5.6. The grading demonstrates the deltaic nature of the sediments, ie. the poorly graded nature and small fines content (<2% silt and clay size). At the Twelve Mile quarry the -19mm aggregate is scalped out to obtain an M/4 grading (pers comm L Matchett). If a similar method was used at the Twelve Mile delta source area Fig. 5.6 indicates that approximately 75% of the aggregate would be scalped out, which is a low recov-

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

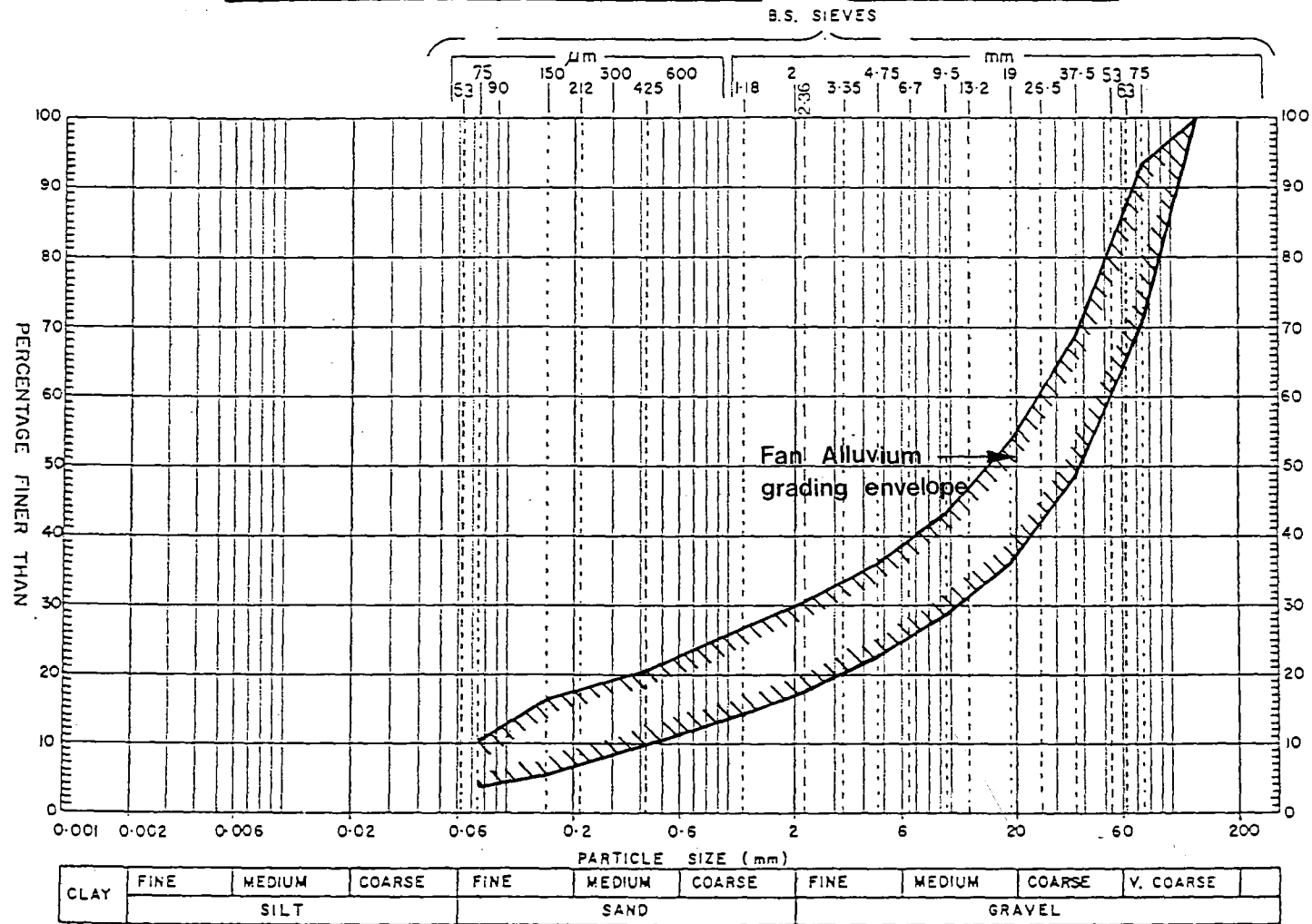


Fig. 5.4 Grading envelope of fan alluvium samples.

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

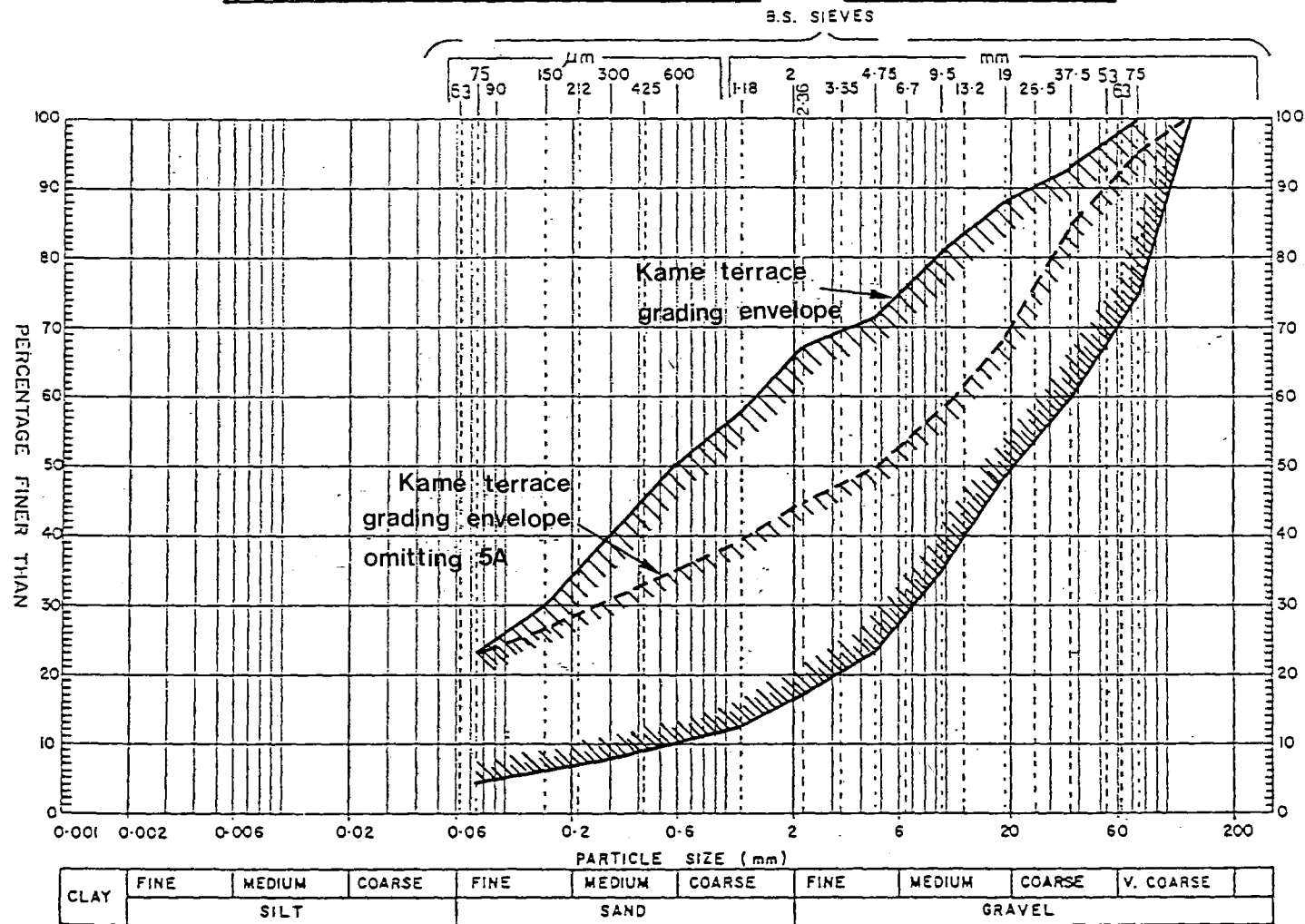


Fig. 5.5 Combined kame terrace and fan alluvium grading envelopes.

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

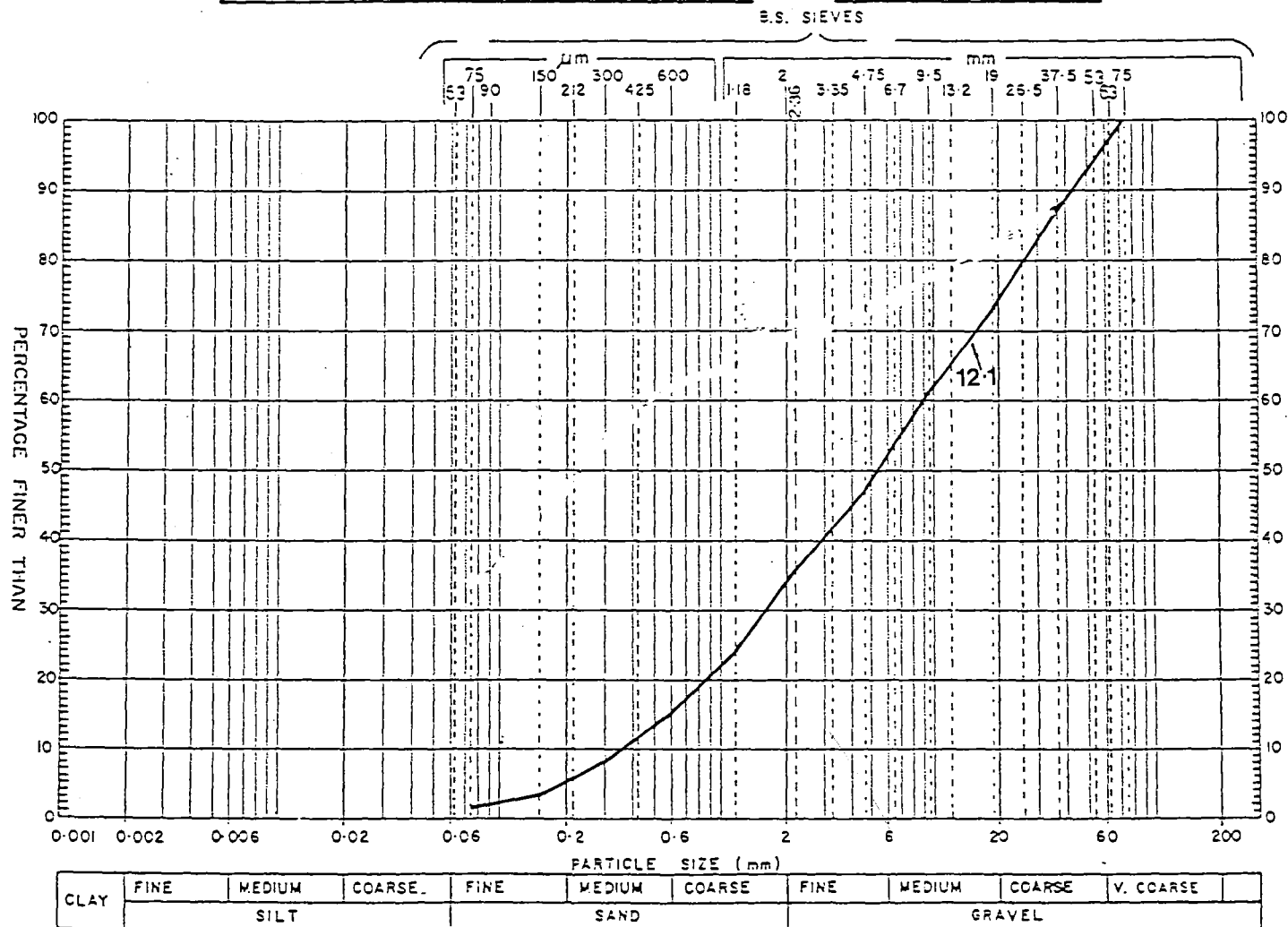


Fig. 5.6 Particle size distribution of Twelve Mile + 45m delta sample 12.1.

ery. However, if a similar method to the Farry quarry is used (ie. -4.75mm scalped out) approximately 50% would be removed, which would be a suitable recovery for the production of basecourse.

### 5.2.3 Crushed Aggregate Particle Size Distributions Results

Gradings of the of the all-in crushed alluvial fan samples 15C, 16C and 17C are represented in Fig. 5.7, and gradings of the scalped/crushed alluvial fan samples 14SC, 13SC and 12SC are represented in Fig. 5.8.

The all-in crushed fan alluvium samples (15C, 16C and 17C) all miss the M/4 AP40 grading envelope, because of an excess of medium-fine sand and silt size material. The excess of sand and silt suggests that scalping is necessary to produce an M/4 grading from the alluvial fan material.

The scalped/crushed fan alluvium samples (14SC, 13SC and 12SC) all miss the M/4 AP40 grading curve. All the gradings contain excess fine, medium and coarse gravel. However, it is suggested that if attention was paid to the grading during production, a M/4 AP40 grading would be obtainable from the scalped/crushed fan alluvium aggregate.

The hydrometer analysis of 17C (Fig. 5.8) demonstrated that the fines are dominantly silt size, the clay size making up only 1% of the total sample mass. The hydrometer analysis of 14SC (Fig. 5.8) demonstrates a similar grain size distribution to 17C, with the majority of the fines being silt size and only 0.5% of the total sample being clay size.

"N" values of the scalped/crushed sample 14SC indicate that the roading aggregate has few fines, grain to grain contact and variable density. This sample lies outside the M/4

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

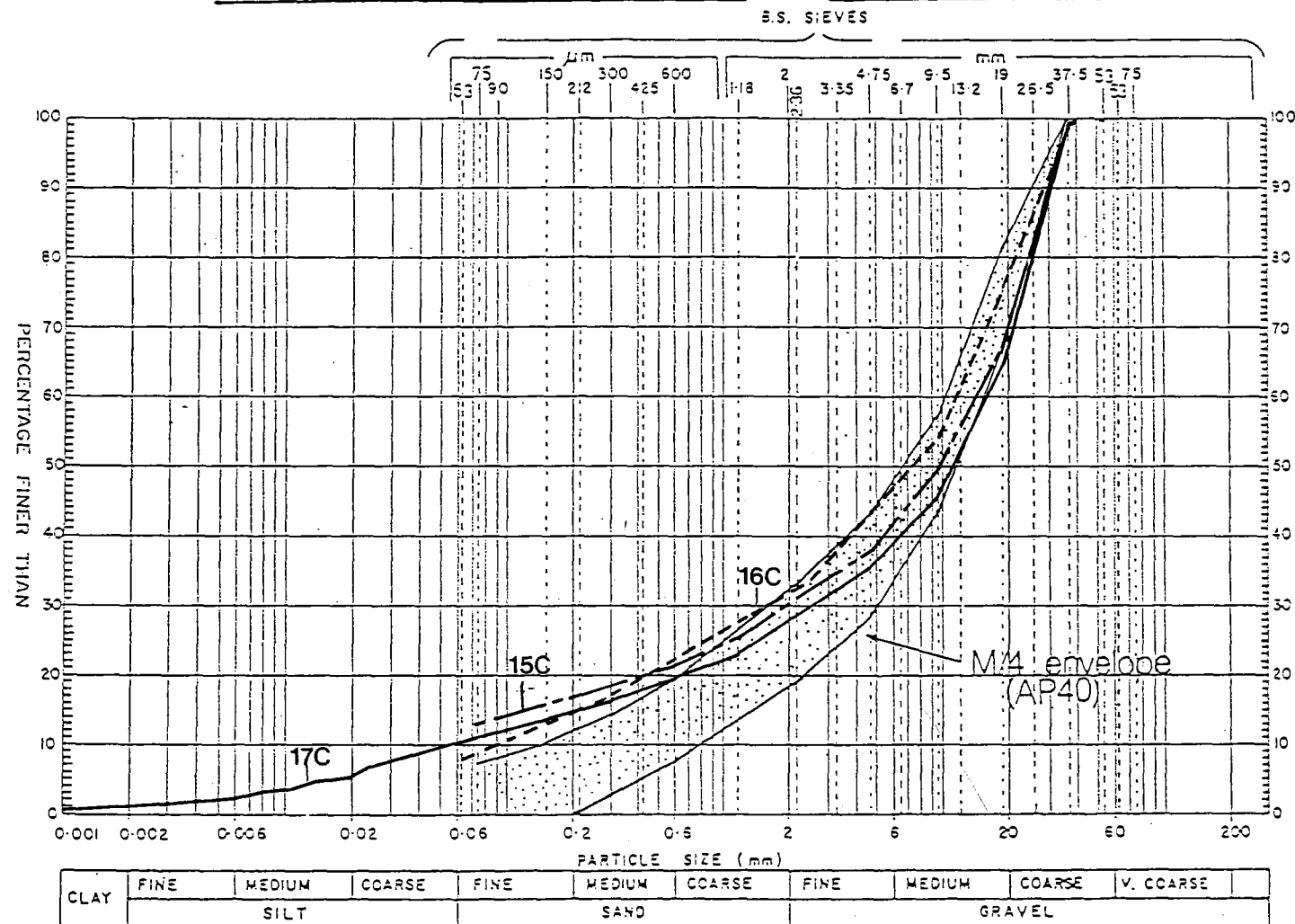


Fig. 5.7 Particle size distribution of all-in crushed fan alluvium samples.



# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

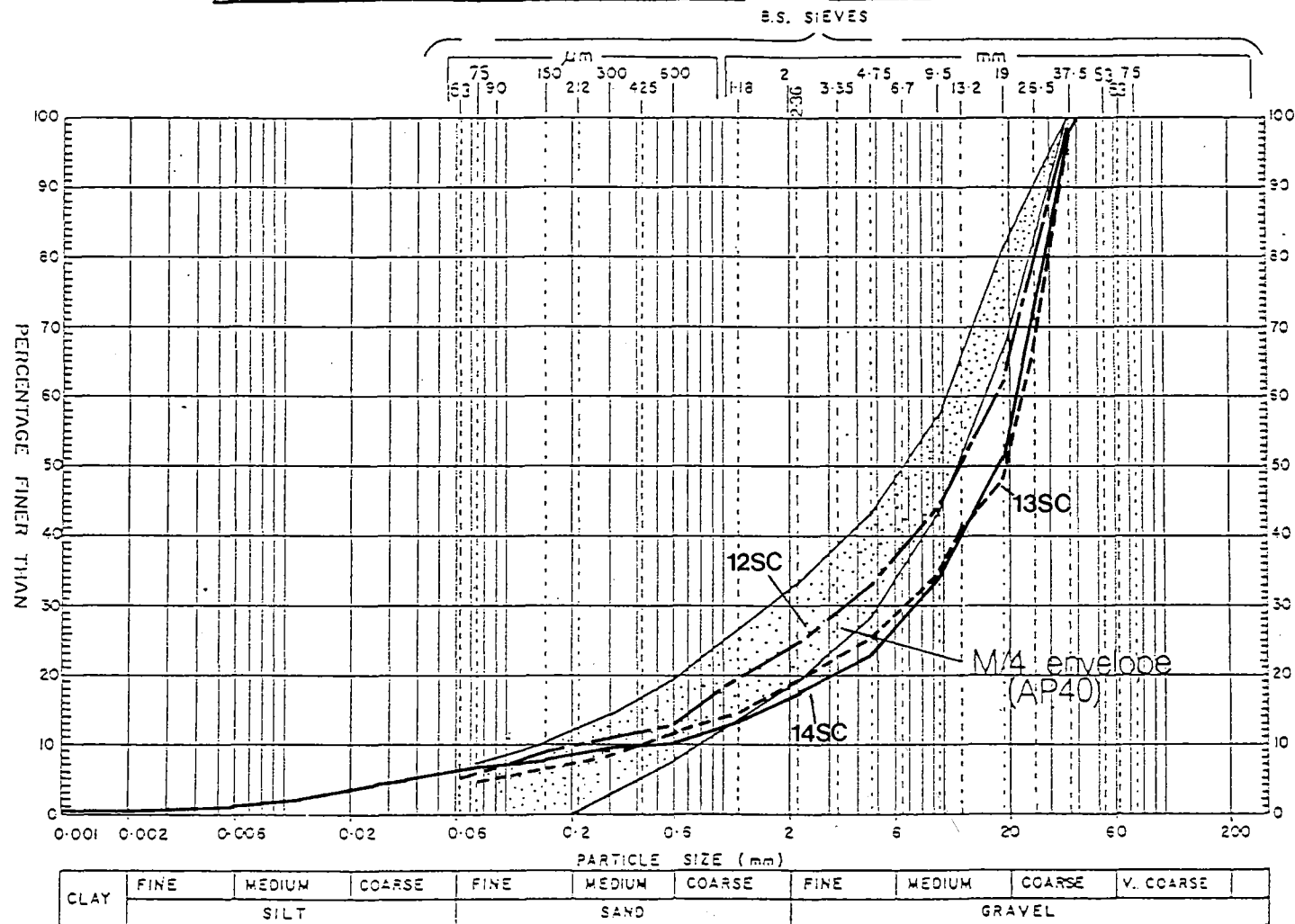


Fig. 5.8 Particle size distribution of scalped/crushed fan alluvium samples.

envelope "n" values (Table 5.4). The remaining two scalped/crushed samples have "n" values within the M/4 envelope, suggesting that the roading aggregates have suitable densities but are slightly deficient in fines to obtain a maximum density. The average "n" value of the scalped/crushed aggregates are similar to "n" values obtained at the Lumberbox (eg. 0.52).

The excess of silt and sand size material in the crushed aggregate is also depicted by low "n" values (Table 5.4). All three crushed samples have "n" values in the fine fraction (1.18mm-75um) of below 0.4, and average "n" values of 0.42, indicating that the aggregate has a large amount of fines and is below the maximum density. However, the average "n" value is within the M/4 envelope "n" values of 0.40 and 0.60.

### 5.3 PROPORTION OF BROKEN FACES

#### 5.3.1 Proportion of Broken Rock Test

The NRB M/4 specification requires each size fraction to have not less than 70% by weight of aggregate clasts with two or more broken faces. This test is used to define aggregates that have properties that effectively match a quarried product (ie. clasts have broken faces). The "Proportion of Broken Rock" test measures the percentage by weight of rock having two or more broken faces in each of the three aggregate fractions 37.5-19.0mm, 19.0-9.5mm and 9.5-4.75mm.

#### 5.3.2 Proportion of Broken Rock Results

The proportion of broken faces of the alluvial fan

crushing trial samples are presented in Table 5.5. All of the samples meet the NRB M/4 specifications for proportion of broken faces.

The scalped/crushed aggregate fractions 19.0-9.5mm and 9.5-4.75mm contain a higher proportion of broken faces than the 37.5-19mm fraction. This is expected as these size fractions are crushed from material larger than 19mm, as all of the -19mm fraction had previously been scalped out.

#### 5.4 SAND EQUIVALENT

##### 5.4.1 Test Method

The sand equivalent test was completed in accordance with NZS 4402 Part 1:1980 Test 7 using air-dried soil samples passing a 4.75mm sieve and the hand-shaking method. The NRB M/4 specification requires the sand equivalence to be not less than 40. A brief outline of the sand equivalent test procedure is provided in Appendix 10.

The sand equivalent test measures the relative amounts of silt and clay-size particles in the aggregate. The specification controls the proportion of the silt and clay-size material, which may have a deleterious effect reducing the aggregate's permeability, creating excessive pore pressures and lowering shear strength of the aggregate when wet.

Gunderson (1979) has raised doubt concerning what the sand equivalent test measures, and whether the test results are reproducible. Salt (1979) also raises doubt about the sand equivalent test and demonstrates that there is a poor correlation between sand equivalent values and basecourse performance in the Christchurch district, Wathey (1984) com-

Scalped/crushed samples				All-in crushed samples		
Sample Fraction	12SC	13SC	14SC	15C	16C	17C
37.5 - 2.36mm	0.58	0.51	0.78	0.5	0.42	0.53
1.18mm - 75um	0.46	0.49	0.49	0.36	0.37	0.38
37.5mm - 75um	0.52	0.50	0.63	0.42	0.39	0.45
Average "n"	0.42			0.55		

Table 5.4 "n" values of scalped/crushed and all-in crushed fan alluvium.

Sample No.	Percent sample retained on sieve with two or more broken faces.		
	19.0mm	9.5mm	4.75mm
14SC	86	95	96
12SC	84	93	97
17C	84	87	85
16C	86	85	81
15C	84	83	78

Table 5.5 Proportion of broken rock in crushed fan alluvium samples.

ments on a similar relationship in the Wakatipu Basin. In many cases the sand equivalent test has been a good indication of quality basecourse and subbases when related to known performances in pavements, but there are a considerable number of exceptions (Ferguson 1979).

#### 5.4.2 Uncrushed Aggregate Results

The sand equivalent values for samples 12.1, 7A and 6A are presented in Table 5.6.

The sand equivalent values for 6A and 7A both fail to meet the M/4 sand equivalent specification, with values of 32 and 25, suggesting that problems may be encountered in obtaining M/4 standard sand equivalent values for crushed aggregate produced from this material. Low sand equivalent values are typical of the glacial derived material of the Wakatipu Basin such as the Lumberbox quarry (discussed in section 3.2.3). Glacial silt occurs as lenses and adheres to the gravel clasts within these deposits. Scalping removes the silt lenses, but the silt adhering to the aggregate clasts survives production.

The Twelve Mile +45m deltaic source area has a sand equivalence of M/4 quality. A suggested reason for the high sand equivalence value of 86, is the small amount of silt and clay size material present in the sample ie. <2% as opposed to 47% of sand and fine gravel (Fig. 5.6). The high sand equivalence value corresponds well with similar deposits at the Twelve Mile quarry which has values of 40-60.

#### 5.4.3 Crushed Aggregate Results

The sand equivalent values for 14SC, 15C, and 17C are also presented in Table 5.6. A sand equivalent test was not

Geotechnical test	Uncrushed aggregate samples				Crushed aggregate samples				
	6B	6A <sup>±</sup>	7A <sup>±</sup>	12.1	12SC	14SC	15C	17C	M/4
Weathering Resistance	-	-	-	CA	CB		CB		AA, AB, AC, BA, BB, CA
Crushing Resistance	-	220KN	180KN	150KN	140KN		140KN		>130KN
Los Angeles Abrasion	-	-	-	42%	40%		41%		NRB M/5 1969 30%
Sand Equivalent	-	32	25	86	-	55	33	36	40
"n" values	-	-	-	-	0.52	0.63	0.42	0.45	0.4-0.6
Clay Index	2	-	-	1	-	1	-	2	NA
Plasticity Index -425um	NP	-	-	NP		NP	-	NP	NRB M/4 1969 5
-75um	NP	-	-	NP	-	NP	-	NP	NA

±: Tested by MOWD Alexandra.

NP: Non-plastic.

Table 5.6 Test results summary of the kame terrace and Twelve Mile +45m delta source areas.

carried out on 12SC because the sample was dry sieved, therefore the fines content and quality may not have been representative.

The all-in crushed samples 15C and 17C which have sand equivalent values of 33 and 36 both fail to meet the M/4 sand equivalent standard, having values similar to 6A and 7A. This is to be expected, since the fines of 15C and 17C were not scalped out and will have passed through the crushing process basically unchanged except for the addition of fines produced by crushing.

The scalped/crushed fan alluvium sample 14SC has a sand equivalent value of 55, which meets the M/4 sand equivalent requirement. The increase in sand equivalent value is suggested to have been produced by the scalping process, which removes fines before crushing, but with the exception of silt adhering to clasts.

Sand equivalent values obtained for scalped/crushed (ie. 55) and all-in crushed (ie. 33 and 36) aggregates are higher than those obtained at the Lumberbox quarry (ie 18-36) and lower than those obtained at the Mount Cook quarries (ie. 85). The Lumberbox and Mt Cook Group quarries, and the proposed Queenstown-Lakes District Council quarry are glacial, or derived from a glacial deposit, and have similar engineering geological descriptions. It would appear from sand equivalent values of these deposits that a wide variation in sand equivalence can be expected, ranging from 18 (Lumberbox) to 86 (Mt Cook Group).

## 5.5 WEATHERING RESISTANCE

### 5.5.1 Weathering Resistance Test

This test was completed in accordance with NZS 3111: Test 15 (1980). The NRB M/4 specifications require a quality index of AA, AB, AC, BA, BB, or CA. (see Table 5.7 for Method of determining the Quality Index). A brief outline of the test is included in Appendix 10.

The Weathering Test is designed to determine the ability of an aggregate to withstand weathering in a stock pile, which is an important property as any change in grading will affect the performance of the aggregate. De Bock (1982) remarks that, contrary to common belief, the weathering resistance test provides an indication of the behavior of the material in an exposed stockpile, and does not indicate the durability of an aggregate in a road structure.

### 5.5.2 Uncrushed Aggregate Results

The uncrushed Twelve Mile +45m delta sample (12.1) meets the National Roads Board M/4 weathering resistance requirement, having a quality index of CA. Sample 12.1 has a cleanness value of 93 and weathering resistance of 90%. Due to the uncrushed nature of sample 12.1 problems arose during the rolling phase of the testing procedure, because the sample was pushed aside, rather than being compacted. De Bock (1982) has commented on similar problems when testing partially crushed aggregate. The ineffective rolling is thought to lessen the attrition incurred by the uncrushed aggregate sample. Therefore, the quality index of sample 12.1 will be increased, but the degree of increase is unknown.

No other weathering resistance test results have been



completed on aggregate from the Twelve Mile area. However, a CA, CB, BA and BB quality index is suggested to be indicative of the Twelve Mile +45m deltaic material.

### 5.5.3 Crushed Weathering Resistance Results

The results of the weathering resistance tests are presented in Table 5.6.

The weathering resistance, crushing resistance and Los Angeles abrasion tests require samples of similar size fractions. Therefore, it was necessary to combine the gravel fraction of fan alluvium samples 12SC and 14SC to produce a sufficient sample of scalped/crushed aggregate. The gravel fraction of fan alluvium samples 15C and 17C were also combined to produce a sufficient sample of crushed aggregate.

The crushed sample 17C/15C and the scalped/crushed sample 12SC/14SC both failed to comply with the M/4 weathering resistance standards. However, both samples are close to complying with the M/4 specification. Sample 12SC/14SC has a cleanness value of 87 and weathering resistance of 87%. Sample 15C/17C has a cleanness value of 89 and a weathering resistance value of 87% (refer Table 5.7 Method for Determining the Quality Index). Therefore, both samples are close to a BA quality index. Two weathering resistance test results can only suggest the quality index of the aggregate, but once roading aggregate is in production at the Queenstown-Lakes District Council quarry, further tests will enable a better estimation of the quality index.

The weathering resistance and cleanness values for the crushed fan alluvium samples 12SC/14SC and 15C/17C are almost identical. This is to be expected, as the gravel fraction of each sample is produced by the crushing of aggregate from the

same source area. The CB index of the kame terrace source area aggregate compares well with the BA quality index of the Lumberbox aggregate, and it would appear that the weathering resistance tests produce consistent results for this type of aggregate.

## 5.6 CRUSHING RESISTANCE

### 5.6.1 Crushing Resistance Test

This test was completed in accordance with NZS 3111:1980 Section 14 "Method for Determining Crushing Resistance of Coarse Aggregate". The NRB M/4 specification requires a crushing resistance of greater than 130kN. However, the NRB M/4 specification notes advise that a crushing resistance of less 130kN does not necessarily preclude their use where stronger aggregates are not available. To use the <130kN crushing resistance aggregates for a basecourse, regional basecourse variance (M/5 Specification) must be approved from Ministry of Works and Development Head Office. A brief outline of the crushing resistance test is provided in Appendix 10.

The crushing resistance test provides an indication of the strength of an aggregate, and the crushing resistance value provides an estimation of the ease of processing and of susceptibility to attrition during mechanical handling of aggregates.

De Bock (1982) comments that New Zealand aggregates demonstrate a relationship between crushing resistance of rounded (crushed) and angular (uncrushed) particles of the same material. The crushing resistance values of rounded

(uncrushed) aggregate are approximately 40-80kN greater than the equivalent angular (crushed) aggregate .

#### 5.6.2 Uncrushed Kame Terrace Source Area Crushing Resistance

##### (i) Kame Terrace Source Area Results.

The crushing resistance results of 6A and 7A are presented in Table 5.6.

Both samples meet the NRB M/4 requirement for crushing resistance, however because the NRB M/4 specification is for crushed aggregate, uncrushed aggregate and the M/4 specification are difficult to compare. De Bock's (1982) approximation states that crushing resistance values of rounded (uncrushed) aggregates are approximately 40-80kN greater than the equivalent angular (crushed) aggregate. Therefore, the crushing resistance value of the crushed kame terrace aggregate is expected to be approximately 140-180kN (ie.  $220\text{kN} - 80-40\text{kN} = 140-180\text{kN}$ ). The approximate crushing resistance value of the alluvial fan material (ie. 7A) is expected to be between 100-140kN.

The difference in crushing resistance values of 6A and 7A is thought to be related to the greywacke content of the samples. Sample 6A is a channel sample collected from kame terrace material, and as demonstrated in Table 5.10, the kame terrace material contains a higher percentage of greywacke in each gravel fraction and particularly the crushing resistance sample fraction (ie. -12.7mm to +9.5mm).

##### (ii) Queensbury Dam Investigations Results.

Salt (1982) carried out aggregate investigations for the proposed Queensbury Dam site on aggregates derived from

Otago Schist and Torless (ie. greywacke-argillite assemblage) basement (Coombs et al 1976) to produce a mixed schist (TZ III and IV), greywacke and quartz aggregate. Salt also notes the above relationship of increasing crushing resistance, with increasing greywacke content, but comments that the trend is not highly consistent.

(iii) Clyde Dam Investigations.

Caples Group greywacke comes from a different source area and paleo environment to that of the Torless greywacke, and it is therefore expected to have different geotechnical properties. However, due to the low metamorphic grade and lack of schistosity, both types of greywacke (Torless and Caples) will have a higher crushing resistance value than schist.

The greater strength of greywacke aggregate is demonstrated by testing completed during aggregate investigation for the Clyde Dam (Jacka 1985). Aggregate investigated was a mixed schist, quartz and greywacke aggregate derived from the Otago Schist and Torless basement. Uncrushed crushing resistance and Los Angeles abrasion tests were carried out on each of the different rock types (Table 5.8). In these tests the greywacke demonstrates twice the crushing and abrasion resistance of schist. It is interesting to note that when using De Bock's (1982) approximation for crushed aggregate the crushing resistance value for the schist sample would be approximately 100kN, which simulates the crushing resistance values obtained for crushed schist aggregate of the Wakatipu Basin.

(iv) Mt Cook Group Quarries Results

Uncrushed crushing resistance tests have been carried

Cleanness value	Percent retained on 4.75mm sieve.		
	96 - 100	91 - 95	up to 90
91 - 100	AA	BA	CA
71 - 90	AB	BB	CB
up to 70	AC	BC	CC

Table 5.7 Quality index values for the weathering resistance test.

Lithology Type.	Los Angeles, %.	Crushing resistance, kN.
Quartz	40	190
Schist	51	140
Greywacke	19	340

Table 5.8 Los Angeles abrasion and crushing resistance values of each lithology type from the Earnscleugh tailings (Jacka 1985).

out by Bell (1980) on kame terrace and alluvial fan samples from the area of the Mount Cook aggregate quarry (Table 3.2). The kame deposits that form the Mt Cook quarries are the northern extension of the kame terraces that are exposed in the kame terrace source area. The visual description (greywacke content), grading, and depositional environment of the two sites are similar, and as expected, the crushing resistance value of the sites compare well. These results indicate that typical uncrushed crushing resistance values for the kame and alluvial aggregates are between 165kN and 220kN

These preliminary crushing resistance tests suggest that the kame terrace source area (proposed Queenstown-Lakes District Council quarry) aggregate is capable of producing roading aggregate with a crushing resistance that complies with the NRB M/4 standard, or is similar to roading aggregate presently used for basecourse in the Wakatipu Basin.

#### 5.6.3 Twelve Mile +45m Delta Source Area Results

The crushing resistance result of sample 12.1 (Table 5.6) meets the NRB M/4 requirement for crushing resistance. However, when De Bock's (1982) approximation is applied, the crushed aggregate is estimated to have a crushed crushing resistance of between 70-110kN. Crushed aggregate crushing resistance values for material in the Twelve Mile area of similar visual description, grading and paleo-environment have values ranging from 100-140kN (Lindsay 1987 and Wathey 1984). These results suggest that De Bock's approximation is valid for schist derived aggregate.

This preliminary test indicates that the Twelve Mile +45m delta source area contains aggregate capable of producing similar crushing resistance values to other aggregates in

the Twelve Mile area. However, problems may arise when attempting to produce roading aggregate that consistently meets the NRB M/4 crushing resistance requirement, as crushing resistance results vary between 100-140kN.

#### 5.6.4 Crushed Aggregate Crushing Resistance Results

The crushing resistance results of scalped/crushed fan alluvium sample 12SC/14SC and all-in crushed fan alluvium sample 15C/17C from the kame terrace source area are presented in Table 5.6. Both of these samples comply with the NRB M/4 specification for crushing resistance. However, the greywacke content of these samples are approximately 10% (Table 5.12), which may not influence the crushing resistance. Crushing resistance samples consist of aggregate which passes the 12.7mm sieve and is retained on the 9.5mm sieve. The greywacke content of this fraction is approximately 4% (Table 5.12), and it is unlikely if this small amount of greywacke will increase the crushing resistance. Typically, schist-derived aggregates with low (ie. <10%) greywacke content produce crushing resistance values of 100-110kN (eg. Shotover roading aggregate). Therefore, the crushing resistance values of the fan alluvium samples 12SC/14SC and 15C/17C may be influenced by other factors.

It is postulated that because these aggregates are glacial-derived and have survived the glacial environment, the "weaker" meta-pelitic schist will have been broken down and removed by glacial attrition, leaving a majority of "stronger" meta-psammitic schist as the gravel fraction. Kame terrace and alluvial fan aggregate are derived from glacial material, and therefore may contain proportionally more stronger natured meta-psammitic schist, which produce the

higher than normal crushing resistance values.

The kame terrace aggregate contains a higher percentage of greywacke than the alluvial fan material, therefore it is inferred that kame terrace aggregate will produce roading aggregate with a crushing resistance greater than that of the alluvial fan material. Using De Bock's (1982) approximation, the crushing resistance of the crushed alluvial fan material was expected to be 100-140kN, the recorded value was 140kN. Based on these results, it appears that De Bock's estimation is valid as a rule of thumb measurement. Therefore, an estimation of the crushing resistance of the kame terrace material would be approximately 140-180kN, which compares well with the Lumberbox aggregate which contains a similar content of greywacke and has a crushing resistance of 180-190kN.

## 5.7 LOS ANGELES ABRASION TEST

### 5.7.1 Los Angeles Abrasion Test

The Los Angeles Abrasion test was completed in accordance with Ministry of Works and Development Central Laboratories Des C 114 69. A brief outline of the Los Angeles abrasion test procedure is provided in Appendix 10. Prior to 1974 the Los Angeles Abrasion test formed part of the NRB M/5 specifications. The required Los Angeles Abrasion value was 30.

The purpose of the Los Angeles abrasion test is to estimate aggregate resistance to abrasion. The Los Angeles abrasion test was included in this geotechnical appraisal as some doubt has been expressed as to the ability of schist derived roading aggregate from the Wakatipu Basin to withstand abrasion (pers comm, A Julius, Ministry of Works and



Development Laboratory Supervisor, Alexandra). Experience with schist aggregates have demonstrated poor Los Angeles Abrasion results (40%) and medium crushing resistance values (110-130kN).

#### 5.7.2 Uncrushed Los Angeles Abrasion Test Results

The Los Angeles Abrasion value of Twelve Mile +45m delta sample 12.1 is presented in Table 5.6. This sample also failed to meet the now redundant NRB M/5 (1965) specification with an abrasion loss of 42%.

As discussed in section 5.3, the lack of resistance to abrasion is suggested to be indicative of a schist-derived aggregate. The Los Angeles Abrasion values suggest that the Twelve Mile +45m deltaic aggregate is susceptible to mechanical degradation. The effect on Los Angeles Abrasion values when using a crushed sample, as opposed to an uncrushed sample of the same aggregate, is not known. However, a similar trend to the crushing resistance test is expected. Therefore, it is reasonable to assume that the Los Angeles abrasion percentage for a crushed sample from the Twelve Mile +45m delta aggregate would be higher than 42%.

#### 5.7.3 Crushed Los Angeles Abrasion Test Results

The Los Angeles Abrasion test results of crushed fan alluvium samples 12SC/14SC and 15C/17C are represented in Table 5.6. Both samples failed to meet the now redundant NRB M/5 (1965) Los Angeles abrasion specification of 30, having abrasion values of 40% and 42%. Results indicate a lack of resistance to abrasion, and this may be indicative of schist-derived aggregate.

The Los Angeles abrasion values of the crushed aggre-

gate are higher than values obtained from the Lumberbox quarry which has abrasion values of 22-29% (Wathey 1984). The difference between the abrasion values of the Lumberbox and alluvial fan roading aggregate is suggested to be related to the greywacke content of the Lumberbox aggregate (ie. 30-40%). The high abrasion resistance of greywacke is demonstrated by Table 5.8.

## 5.8 LITHOLOGICAL ANALYSIS

### 5.8.1 Lithological Analysis

There is no New Zealand standard for lithological analysis. The following method was used, material retained on the 75mm, 37.5mm, 19.0mm, 9.5mm, and 4.75mm sieves during the sieve analysis were used for the lithological analysis. The material retained on the sieve was sorted in to separate lithologies and the percentages of the different lithologies calculated by weight. The purpose of the lithological analysis was to establish the lithology of the different units and to see how the lithology relates to the depositional environments and geotechnical properties.

Four different lithological groups were used for the analysis (quartz, schist, greywacke and other) and are defined as follows:

(a) quartz - any aggregate clast that contains more than 75% quartz;

(b) schist - any clast that consists of textural zone II, III and IV schist (Bishop 1972);

(c) greywacke - rockse derived from the Caples Group (Coombs et al 1976); and

(d) other - any lithology that does not fit the previ-

ous definitions.

The quartz definition is used because it is assumed that any clast that consists of more than 25% schist will be dominated by the schist geotechnical properties.

Problems with reliability of the analysis on the 75mm and 37.5mm sieves were identified during testing. Unreliable results were obtained for sample 12.1, as the material retained on the 37.5mm sieve consists of eleven clasts, two of the larger clasts are greywacke and have biased the sample. To provide an indication of the reliability of the results, the number of clasts and the corresponding mass of the lithological sample are provided.

#### 5.8.2 Uncrushed Samples

The results of the lithological analysis of the uncrushed aggregate samples of the kame terrace and Twelve Mile +45m delta source areas are presented in Appendix 11.

The lithological analysis of the Twelve Mile +45m deltaic aggregate suggests that < 5% greywacke is present within the deposit. The 45% greywacke recorded in the >37.5 fraction is unreliable as the sample number of clasts is eleven.

Lithological analysis of till sample 11A from the kame terrace source area (Appendix 11) indicates that till material has a higher greywacke content than the kame terrace aggregate. This is to be expected, since the kame terrace material was derived from glacial material and local schist derived aggregate from The Remarkables.

Analyses demonstrate that the lithology of the kame and alluvial deposits of the kame terrace source area are variable, however the two deposits are lithologically distinct and this is depicted by the composite lithological analysis

Table 5.9 and 5.10. The average percent of greywacke retained on the sieves for the kame terrace aggregate is 21% as opposed to 12% for the alluvial fan aggregate. This result is to be expected since the fan alluvium is derived from reworked kame terrace material and local schist derived aggregate.

Composite lithological analysis demonstrates that the kame terrace aggregate contains an average of 35% greywacke on the 37.5mm sieve and a lower average for each of the smaller sieve sizes. Fan alluvium contains an average of 16% greywacke on the 37.5mm sieve and a lower average for each of the smaller sieve sizes. This general trend of reducing greywacke content and reducing clast size is also depicted by the composite lithological analysis of the Queensbury aggregate (Table 5.11). One envisaged reason for this is that the greywacke aggregate has a preferred clast size, which may be related to joint sizes of the parent rock.

#### 5.8.3 Crushed Samples

As expected, the lithological analysis shows no difference between the greywacke content of the all-in crushed and scalped/crushed samples (Appendix 11). The composite lithological analysis indicates that only a small (<10%) percentage of the all-in crushed and scalped/crushed samples consist of greywacke (Table 5.12).

### 5.9 ATTERBERG LIMITS

#### 5.9.1 Atterberg Limits Test

The Atterberg limits were determined in accordance with

Lithological Type.	Percent (by weight) sample retained on sieve				
	Fan alluvium				
	75mm	37.5mm	19.0mm	9.5mm	4.75mm
Quartz	0	7	13	20	18
Schist	100	77	75	68	74
Greywacke	0	16	12	12	8

Table 5.9 Composite average of fan alluvium lithological analysis.

Lithological Type.	Percent (by weight) sample retained on sieve				
	Kame terrace				
	75mm	37.5mm	19.0mm	9.5mm	4.75mm
Quartz	0	8	15	22	26
Schist	65	68	65	60	62
Greywacke	35	24	20	17	11

Table 5.10 Composite average of kame terrace lithological analysis.

Lithological Type.	Percent (by weight) sample retained on sieve. Scalped/crushed and all in crushed samples.			
	137.5mm	19.0mm	9.5mm	4.75mm
Quartz	0	5	10	12
Schist	74	89	86	83
Greywacke	26	6	4	4

Table 5.12 Composite average of scalped/crushed and all-in crushed fan alluvium lithological analysis.

Lithology	Percent sample retained on sieve.				
	75mm	37.5mm	19.0mm	9.5mm	4.75mm
Quartz	26	25	27	36	42
Schist	13	26	28	28	29
Greywacke	61	49	44	35	29

Table 5.11 Composite average of Queensberry lithological analysis (after Salt 1982).

NZS 4402 Part 1:1980 Tests 2, 3, and 5. The samples used were whole samples passing the 4.25mm and 75um sieve. A brief outline of the Atterberg limit tests is provided in Appendix 10.

Prior to 1973 the NRB M/5 specification included Atterberg limits. For an aggregate to comply with the standard, a sample passing the 0.425mm had to be either non-plastic, or had a liquid limit not greater than 25 and a plasticity index not greater than 5. This test was superseded by the sand equivalent test after 1973. Atterberg limit tests are used to determine the range of water contents in which a soil sample will demonstrate plastic behaviour.

One of the reasons for substituting the Atterberg limits with the sand equivalent test in the National Roads Board specifications was because problems were being experienced in obtaining repeatable results for the Atterberg limits (Bartley 1987). In Bartley's view, this substitution of tests within the NRB M/4 specifications was a backwards step as plasticity has a major influence on the stability of a pavement and the sand equivalent test provides no information about the plastic nature of the fines. Therefore, it was considered necessary to include Atterberg limits within the geotechnical tests to establish the plastic nature of the fines.

The liquid limit test becomes impractical to use when working with materials which have a low clay content (approximately <5% clay size material). These generally sandy/silty materials do not adhere to the cup of the liquid limit device and slide rather than flow in a plastic manner. Therefore, the alternative method for determining the liquid limit was used, the cone penetration method. Ackroyd (1985) notes that schist derived sediments from the Wanaka region demonstrated

similar problems when determining the liquid limit. Ackroyd (1985) also used the cone penetration limit to establish the liquid limit.

Whole samples passing the 0.425mm sieve were used, as specified in the standards. Whole samples passing the 75um sieve were also used to obtain liquid and plastic limits, in order to compare results with Sameshiema and Black (1980). Samesheima and Black (1980) have demonstrated a linear relationship between plastic index (when obtained using the -75um fraction) and clay index.

#### 5.9.2 Atterberg Limits Results

The results of the Atterberg limits tests carried out on samples from the kame terrace and Twelve Mile +45 delta source areas are provided in Table 5.6. All of the aggregates tested were non-plastic, with no plastic limits being obtained, either using the -0.425mm sample or the -75um sample. All materials tested behaved in a non-plastic manner. The materials demonstrated dilatant properties and were generally cohesionless and crumbled when rolled.

For all materials tested, the liquid limit was unobtainable, either using the -0.425mm sample or the -75um sample. An attempt to determine the liquid limit using the traditional liquid limit devise was carried out. However, the cohesionless behavior of the material did not allow this test method to be used as the sample slid in the cup.

The alternative method for determining the liquid limit was used, the Cone Penetration method. Problems also arose when using this method. The dilatant nature of the material prevented a true water content from being obtained at differing cone penetrations (Fig. 5.9). The water content and cone



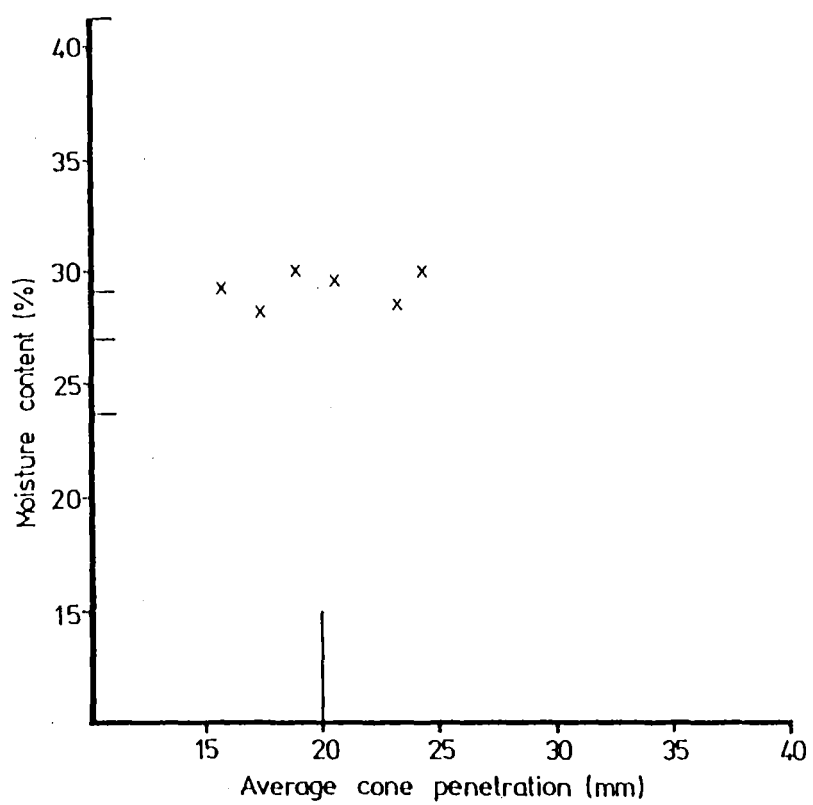


Figure 5.9 Cone penetration test of sample 17C.

penetration limit do not produce a linear relationship, so making the test invalid. The non-linear relationship was expected, as after cone penetration the dilatant effect would extrude free water to the surface, making collection of a true water content sample impossible. The dilatant effect was not present when the sample had a cone penetration of  $<5$ , however this is insufficient to determine a liquid limit. The Cone Penetration test was invalid for the  $-75\mu\text{m}$  and the  $-0.425\text{mm}$  sample fraction.

The non-plastic and cohesionless behavior of samples is a result of the low clay content (ie.  $< 1\%$  of the total sample). The low clay content of these aggregates is shown by gradings of 12.1, 14SC, 17SC and 6B (Fig. 5.6, 5.7, 5.8 and Appendix 9). The dilatant behavior of the test samples also identifies the samples as consisting of mainly silt and fine sand (Head 1980). Both the alluvial fan (14SC and 17C) and kame terrace (6B) samples indicate that aggregate from the kame terrace source area (proposed Queenstown-Lakes District Council quarry) is non-plastic.

Atterberg samples from the Mt Cook Group quarry (ie. kame terrace aggregate) were found to be non-plastic, and a liquid limit could not be obtained. Atterberg limits carried out on all-in crushed basecourse samples from the Lumberbox had plastic index values of 4, and the scalped/crushed basecourse samples were non-plastic (Bartley et al 1986). Ackroyd (1985) completed Atterberg limit tests on schist derived roading aggregate ( $-0.425\text{mm}$ ) samples from the Wanaka region, and comments on the non-plastic and dilatant behavior of the materials. Ackroyd used the cone penetration method for determining the liquid limits, and also records schist derived aggregate as non-plastic.

In summary, it would appear that greywacke and schist derived aggregate of Central Otago are typically non-plastic to slightly plastic, and have a comparatively narrow range of moisture content over which they will behave in a plastic manner. However, the fines are affected by water content and become dilatant at low moisture contents.

## 5.10 CLAY INDEX TEST

### 5.10.1 Clay Index Test

The Clay Index Test was completed in accordance with Ministry of Works and Development AEL Report No. 83/26 by R. High (1983), "Recommended Method of Testing for Determination of Clay Index Value". A brief outline of the clay index test is provided in Appendix 10. Test samples were collected from the wet sieve analysis, and from the -75um fraction of the cleanness test.

The Clay Index provides an indication of the presence of smectite clays within the fine fraction of an aggregate, and was used in this geotechnical appraisal of roading aggregate because of the close relationship demonstrated between the nature of the smectites in the aggregate fines and the plastic properties of the fines. Sameshima and Black (1980) suggest that the clay index, liquid limit and plastic index provide the best practical indicator of swelling clays in roading aggregate fines.

The advantage of the Clay Index value is that the test measures the nature and amount of the clay minerals in the fines, as opposed to the sand equivalence, which measures the amount of silt and clay-sized material in the aggregate.

The clay index test has found general acceptance in New Zealand as a second order test method and has been used in several basecourse evaluation programmes run by the Ministry of Works and Development and the Road Research Unit (Van Barneveldt 1986).

Sameshima and Black (1980) tentatively proposed a specification for basecourse aggregates (see Table 5.13) where the Clay Index value is related to basecourse quality. This was refined by Gray and Orr (1985), who suggested that a modified Clay Index value be used, calculated by the following formula:

$$\text{Clay Index} \times \% \text{ passing } 75\mu\text{m sieve} = \text{Modified Clay Index.}$$

Modified Clay Index values of 10 or less are suggested to be "sound".

During completion of the Clay Index tests a problem was identified when using the "back titration", as this involves subjective comparison of colours. Bartholomeusz (1987) also comments on this problem, and suggests the back titration be omitted if possible. Three other limitations of clay index tests have been commented on by Van Barnnevelt (1986).

"(a) The test method has not been formally standardised and repeatability and reproducibility have not been documented.

(b) The clay index test on its own only provides a measure of the activity of the minus 75 $\mu$ m test mass. The significance of this activity will be tempered by its relative abundance within the total aggregate.

(c) The clay index test is only an indicator of the activity of fines present within the test mass at the time of testing. On its own it does not predict generation of active

fines."

However, two of these limitations can be minimised. The significance of the 75um test mass can partially be quantified by the use of Gray and Orr's (1985) Modified Clay Index value. The activity of fines produced by weathering may be crudely appraised by carrying out Clay Index tests on the weathered fines produced in the weathering test. For these reasons, the modified clay index is used, and clay index tests of weathered fines were carried out in this geotechnical investigation

#### 5.10.2 As Received Fines Results

Results of the clay index tests carried out on samples from the source areas are provided in Table 5.14. All of the samples tested are within the range of sound or poor aggregate, as indexed by Sameshima and Black (1980) (Table 5.13). The results of the clay index test indicate that for all samples tested, contains only a small amount of smectite clay minerals. The clay index values obtained during testing compare well with clay index values from the Lumberbox (Table 5.6) and it is assumed from the results that large amounts (ie. amounts capable of producing unsound roading aggregate) of smectite clays are not expected within the investigated sites.

Using the modified clay index value suggested by Gray and Orr (1985), the samples tested can be described as "sound" to "unsound". Samples 6B and 17C are indexed by the modified clay index value as being "unsound" for aggregate production. The original "good" and "poor" index samples of 6B and 17C have had their index value reduced by the modified clay index test to "unsound" because of high silt con-

Clay index value	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to ...
Aggregate grading	Sound	Good	Poor	Unsound	Unsound

Table 5.13 Clay index grading scale (after Sameshima and Black 1980).

Sample No.	6B	12.1	14SC	17C
Clay index as received	2(2)	2(1.4)	1(1.05)	3(2.3)
Modified clay index	32(32.0)	3(2.8)	7(6.3)	26(25.3)
Clay index generated fines	-	2(1.8)	2(1.95)	3(2.1)

N.B. Calculated values are shown in the brackets, adjusted values fit the clay index grading scale (Sameshima and Black, 1980) are not bracketed (see text for further discussion).

Table 5.14 Clay index results.

tent of samples 6B and 17C. The validity of the modified clay index test to identify an unsound aggregate for roading purposes has not been documented. However, smectite clays within a roading aggregate that contains a large amount of fines is suggested to be unstable and may cause pavement failure.

Sameshima and Black (1980) have demonstrated that there is a linear relationship between clay index values and plasticity index values. However, Atterberg limits for samples 6A and 17C were unable to be determined, suggesting that the clay index test may be identifying other minerals (discussed further in section 5.11.4)

#### 5.10.3 Weathered Fines

The results of the clay index tests carried out on fines produced during the weathering resistance tests are provided in Table 5.14. The samples are within the range of "good" to "poor" aggregate as indexed by Sameshima and Black (1980). All samples indicate that weathering has generated smectite clay minerals. The generation of smectite minerals, in addition to the natural occurring smectites within a roading situation, has the potential to cause the plasticity of the aggregate to increase with weathering which may eventually cause stability problems and pavement failure. However, the mineralogy of the clay size minerals that the clay index test is identifying are conflicting (discussed in section 5.11.4).

## 5.11 X-RAY DIFFRACTION

### 5.11.1 X-ray Diffraction Test

The Dropper-on-glass slide (DOGS) method was used to prepare the X-ray Diffraction slides. A Phillips Universal Diffractometer with Cu K radiation and Nickel filter was operated at 34 KV and 34 MA. A speed of one degree per minute was used. X-ray Diffractograms were run from  $2^0$  to  $30^0$ . A brief outline of the X-ray diffraction procedure is provided in Appendix 10.

X-ray Diffraction analysis of the clay size fraction was completed to provide qualitative information about the nature of the clay size material. The X-ray Diffraction analysis also provides a qualitative check on what type of clay size materials the Clay Index is identifying. The purpose of testing the generated fines produced in the weathering test, was to determine if any change in the composition of the fines had occurred as a result of physical weathering.

For the purpose of this geotechnical investigation it is considered that qualitative identification of the major mineral groups present in the clay size material was sufficient. A detailed mineralogical x-ray analysis and quantitative analysis was not considered appropriate, although, quantitative estimates of the clay minerals were inferred.

For further identification of the clay mineral species, two treatments were used:

(a) the untreated slides were glycolated using ethylene glycol atomiser and x-rayed after the maximum expansion period of thirty minutes; and

(b) untreated slides were heated to  $500^0\text{C}$  for one hour.



### 5.11.2 As Received Fines

Fig 5.10 depict diffractograms of clay size fraction of scalped/crushed fan alluvium sample 14SC in the natural state, treated with ethylene glycol and heat treated to 500<sup>0</sup>. Fig. 5.11 depict diffractograms of clay size fraction of all-in crushed fan alluvium sample 17C in the natural state and heat treated to 500<sup>0</sup>. Table 5.15 represents the d spacings used to identify the clay size minerals.

The minerals identified are quartz, Fe-chlorite or kaolinite, illite and a mixed layered smectite. Illite and Fe-chlorite or kaolinite dominate the assemblage with sharp and well defined peaks. A differentiation between Fe-chlorite and kaolinite was not possible as both minerals have similar d spacings and react to heat treatment in the same manner ie. disappear after heat treatment at 500 C (Fig. 5.10 and 5.11) (Brown 1961). Brown (1961) comments that without additional acid treatment (which was not carried out) a differentiation between Fe-chlorite and Kaolinite can not be made. However, it is probable that the mineral is Fe-chlorite as the sample is derived from schist, as chlorite is commonly found in schist (Brown 1961). Therefore, the author has represented this mineral as Fe-chlorite in Fig. 5.10 and 5.11)

Mixed layered smectites were only identified in sample 14SC, and this was a comparatively small amount. The peak is broad and diffuse, and was reduced in height after treatment with ethylene glycol (Fig. 5.10), thereby identifying the mineral as interlayered smectite. It is not known with what the smectite is interlayered with, as the secondary reflections are not definable above the background noise. Ethylene glycol treatment did not effect any of the other samples and the diffractograms remained unchanged.

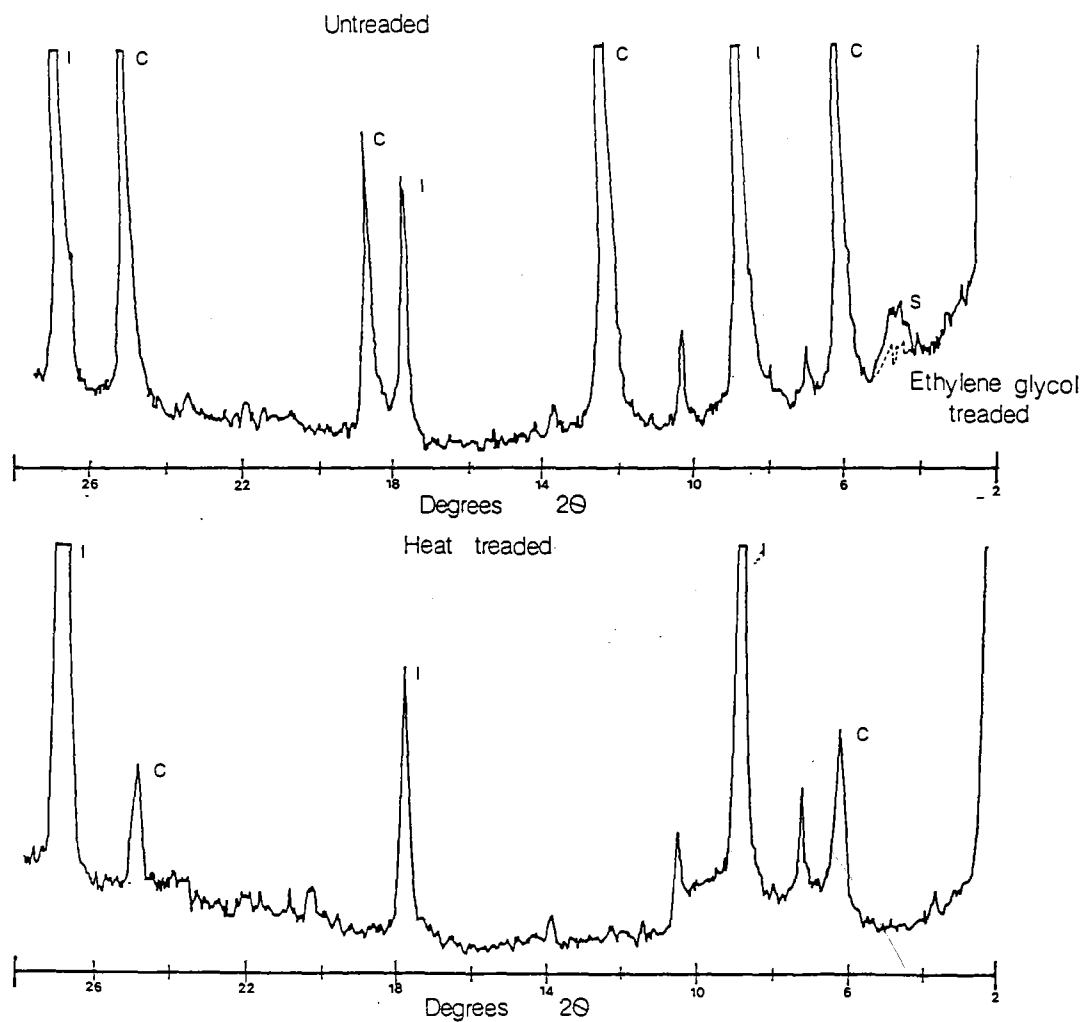


Fig. 5.10 X-ray diffractograms of clay size fraction of scalped/crushed fan alluvium sample 14SC, in the natural state, treated with ethylene glycol and heat treated to 500°. c = chlorite, i = illite, s = interlayered smectite.

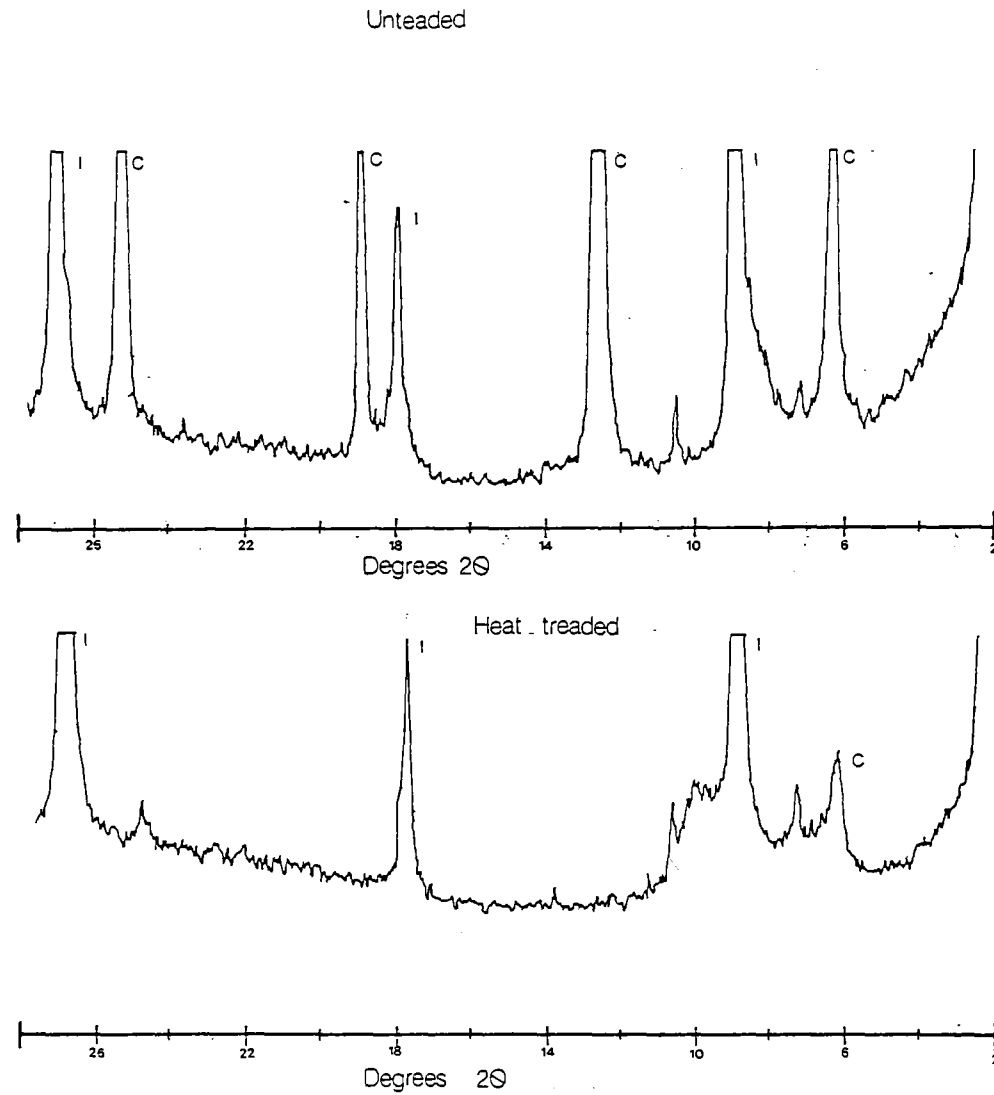


Fig. 5.11 X-ray diffractograms of clay size fraction of all-in crushed fan alluvium, in the natural state and heat treated to 500°. c = chillrite, i = illite.

Mineral	hkl	Principal $d$ spacing used for identification (degrees 2 $\theta$ in brackets)	
Quartz	001	3.34 (26.7)	4.26 (20.9)
Chlorite (Fe)	002	7.05 (12.6)	3.52 (25.3)
Kaolinite	002	7.10 (12.5)	3.56 (25.0)
Illite	002	9.97 (8.9)	3.33 (26.8)

Table 5.15 Identification by x-ray diffraction of clay sized minerals  
(after Berry et al., 1974).

Ackroyd (1985) carried out a X-ray diffraction study on schist derived aggregate of the Wanaka region and identified a similar mineral assemblage to that above, viz. illite, chlorite and minor amounts of interlayered illite/vermiculite. X-ray diffraction runs on clay size material from the Lumberbox, identified the presence of mica (illite) and a mixed illite-chlorite clay (Bartley et al 1986). The results of these studies indicate that clay minerals present in dominantly schist-derived deposits of Central Otago region are mainly the phyllosilicate minerals mica and chlorite.

#### 5.11.3 Weathered Fines

Fig 5.12 and 5.13 depict diffractograms of the clay size fraction of the weathered fines samples 17C and 14SC in the natural state and heat treated to 500<sup>0</sup>. The diffractograms of the weathered fines demonstrate a similar assemblage of clay minerals to the "as received" samples, ie. sharp well defined peaks identified as illite and chlorite, with no smectites. Quartz is identified in the weathered fines samples 14SC and 17C. The primary reflection at 26.7<sup>0</sup> ( $d = 3.34 \text{ \AA}$ ) is obscured by a mica reflection at about the same position. A secondary reflection at 20.7<sup>0</sup> ( $d = 4.29 \text{ \AA}$ ) is thereby considered as diagnostic. The weathered fines and natural fines assemblages are similar, indicating that no compositional change has occurred during the weathering process.

#### 5.11.4 Comparison of X-ray Diffraction and Clay Index Results

Sameshima and Black (1980) have demonstrated that a

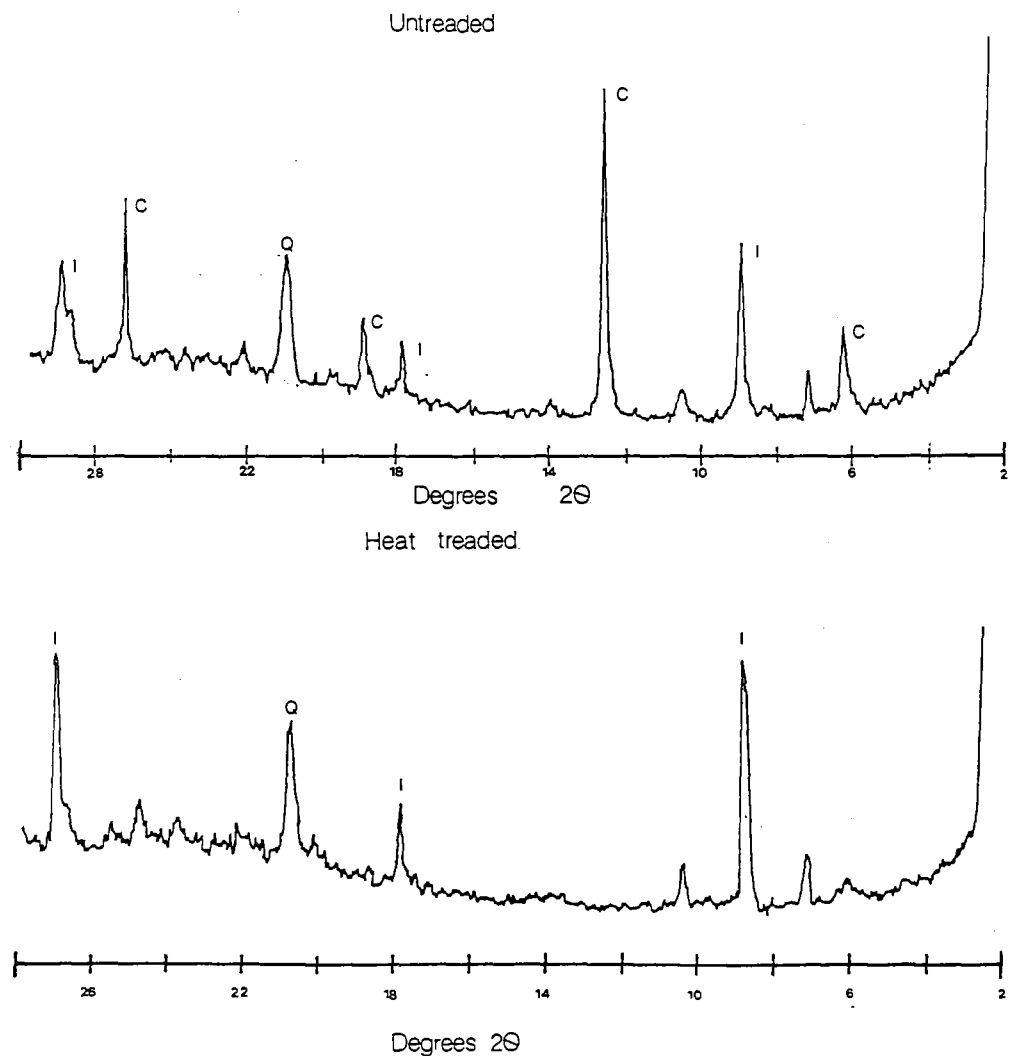


Fig. 5.12 X-ray diffractograms of clay size fraction of the weathered fines sample 14SC, in the natural state and heat treated to 500°. c = chlorite, i = illite.

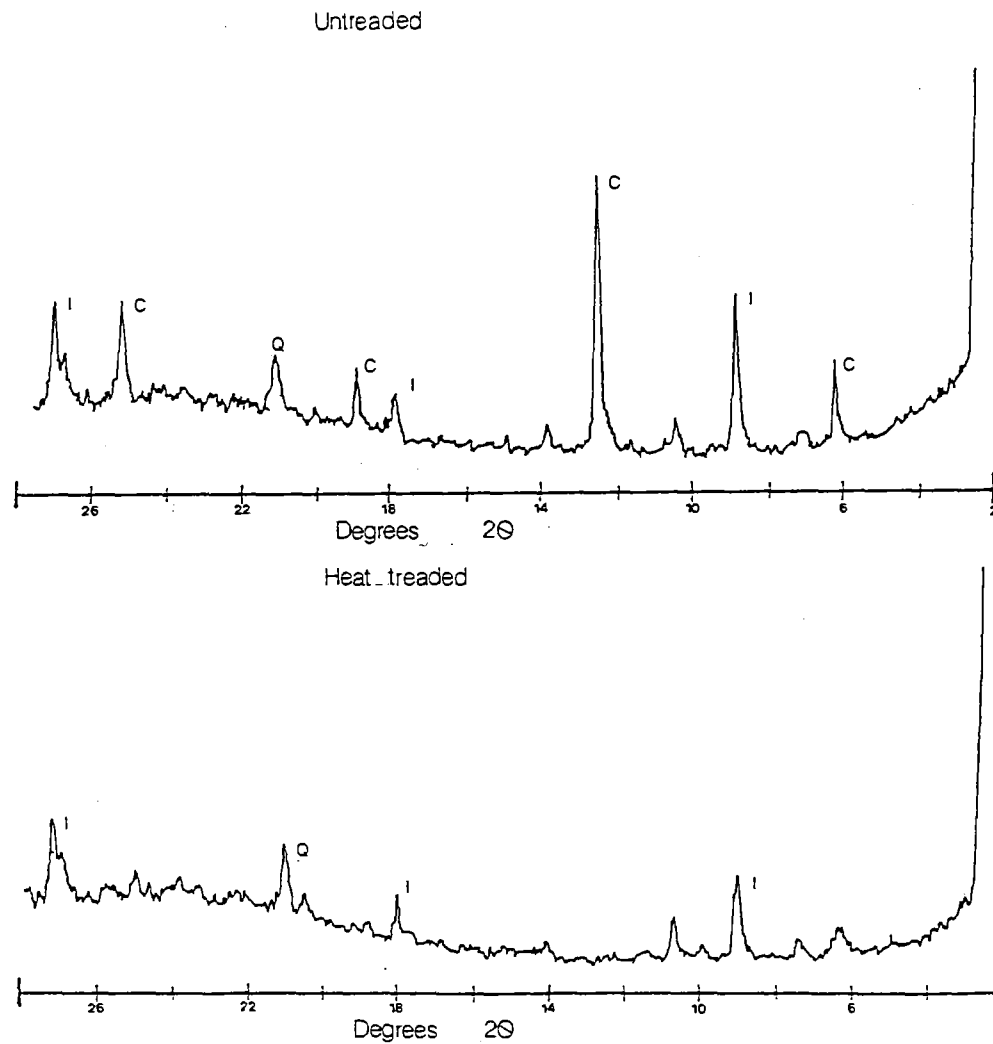


Fig. 5.13 X-ray diffractograms of clay size fraction of the weathered fines sample 17C, in the natural state and heat treated to 500°. c = chlorite, i = illite.

linear relationship exists between smectites and clay index values. As demonstrated by the diffractograms, no smectite mineral were identified within the samples tested, with the exception of a comparatively small amount in sample 14SC, but "good" to "poor" clay index values were obtained in all samples.

Sameshima and Black (1980) also record that mica (illite), chlorite and zeolites, laumontite and heulandite are also identified by the clay index test. Clay index tests carried out on the above minerals, demonstrate their reactivity (Sameshima and Black 1980). Clay Index results of the minerals are as follows; smectites 21-55, mica (illite) 7.3, chlorite 2.4, laumontite 1.7 and heulandite 1.5. Therefore, if a clay index sample contains mica (illite) and chlorite but no smectite, the clay index may still produce "good" or "poor" index values as indexed by Sameshima and Black (1980).

The x-ray diffraction analysis identified chlorite and illite within the clay fraction of the samples, these minerals are also inferred to occur in the larger size fractions. Therefore, the clay index tests carried out on kame terrace and Twelve Mile +45m delta source areas samples are suggested to be identifying illite and chlorite rather than smectites.

## 5.12 DISCUSSION OF TEST RESULTS

### 5.12.1 Uncrushed Aggregate Samples

#### (i) Twelve Mile +45m Delta.

Only one uncrushed sample (12.1) was collected and tested from this source area. Therefore, the results are only indicative of aggregate quality. The deltaic aggregate is



clean and non-plastic, with sufficient course material for crushing. The test results indicate that the deltaic aggregate is capable of producing quality roading aggregate, but as with other schist derived deposits, may have problems meeting the NRB M/4 crushing resistance requirement.

(ii) Kame Terrace Source Area (Proposed Queenstown-Lakes District Council Quarry).

Gradings have demonstrated that a sufficient quantity of coarse aggregate is available from both the kame terrace and fan alluvium deposits for the production of roading aggregate. If the -19mm fraction was scalped out, an average of  $53\% \pm 16\%$  (by weight) of the total mass would be removed. Due to the large amount of aggregate being removed, the author suggests that experimental work with a smaller scalping size (and its affect on grading) be determined. Consideration should also be given to further processing of the scalping for use as a low grade subbase.

The kame terrace aggregate demonstrates a more variable grain size and a higher greywacke content than the alluvial aggregate. The higher greywacke content is reflected in the crushing resistance value. Both deposits are "dirty" and produce low sand equivalent values, but demonstrate non-plastic behavior.

The test results indicate that both the alluvial fan and kame terrace deposits are suitable for producing quality basecourse, but may not meet the NRB M/4 sand equivalent requirement. The low sand equivalent values suggest that further investigation of the fines fraction is required. As discussed in section 5.4.1, there is some doubt as to what the test measures (Gunderson 1979) and its ability to identify

quality basecourse (Ferguson 1979). Therefore, the low sand equivalent values may not limit the use of the aggregates for the production of basecourse.

#### 5.12.2 Crushed Samples

##### (i) All-in and Scalped/crushed Roding Aggregate.

Test results of the all-in crushed and scalped/crushed fan alluvium have demonstrated that there is little difference in the overall quality of the two roding aggregates. The only major difference is, that the all-in crushed aggregates are not capable of complying with the NRB M/4 grading requirement due to an excess of medium-fine sand and silt. Therefore, this suggest that scalping will be required during the production of roding aggregate from the alluvial material. Scalping may also reduce the sand equivalent values.

##### (ii) Coarse Aggregate Fraction (>4.75mm).

As expected, the scalped/crushed coarse aggregate fraction (> 4.75mm) demonstrates almost identical properties to the all-in crushed samples. The coarse aggregate fraction demonstrates medium strength (ie. crushing resistance of 140kN and Los Angeles abrasion of 40%), with an indication that the aggregate may be susceptible to breakdown due to physical weathering within the stock pile, and mechanical handling during construction. Test results indicate that the product of the breakdown is non-plastic, therefore the increase in fines content may not be a detrimental factor, and may in fact result in denser (ie. "n" value between 0.45-0.50), more suitable pavement than would otherwise be the case. However, it is suggested that steps be taken to monitor the breakdown, ie. carry out gradings after stock

piling and pavement construction.

(iii) Fine Aggregate Fraction (<4.75)

Sand equivalent test results of the roading aggregates indicate that problems may arise from plastic fines within the roading aggregates. However, further investigations of the fine fraction have indicated a non-plastic fines fraction with little or no smectite group clays present.

(iv) NRB M/4 Compliance

Scalped/crushed roading aggregate fails to comply with the NRB M/4 specification as it misses the grading and weathering resistance requirement. An M/4 grading would be obtainable if care was taken during production. Weathering resistance quality narrowly misses the M/4 standard, and further testing will provide a better estimation of the quality index. Therefore, these results suggest that the scalped/crushed alluvial fan aggregate from the kame terrace source area (ie. proposed Queenstown-Lakes District Council quarry) is capable of producing NRB M/4 quality roading aggregate.

The all-in crushed aggregate fails to comply with NRB M/4 specifications, as it misses the grading, weathering resistance and sand equivalent requirement. The grading has an excess of fines, and it suggests that scalping is a requirement to obtain an M/4 grading. The weathering resistance test narrowly fails (ie. quality index of CB) to meet the M/4 requirement and further testing of the weathering resistance quality will provide a better indication of the weathering resistance quality.

Similar glacial derived deposits (eg. Lumberbox) to the

kame terrace source area do not comply with the National Roads Board sand equivalent requirement and it is envisaged that the fan alluvium may also produce low sand equivalent values.

(v) Comparison with Lumberbox Roding Aggregate.

Test results of the scalped/crushed roding aggregate infer a similar quality to the Lumberbox roding aggregate (Table 5.16). The Lumberbox produces higher crushing resistance value and weathering resistance index, but the scalped/crushed roding aggregate has a higher sand equivalent value.

As suggested earlier, the proposed Queenstown-Lakes District Council quarry may have similar problems to the Lumberbox quarry in complying with the NRB M/4 sand equivalence. However, roding aggregate from the Lumberbox has performed well, and no stability problems caused by the low sand equivalent values have been identified (Wathey 1984).

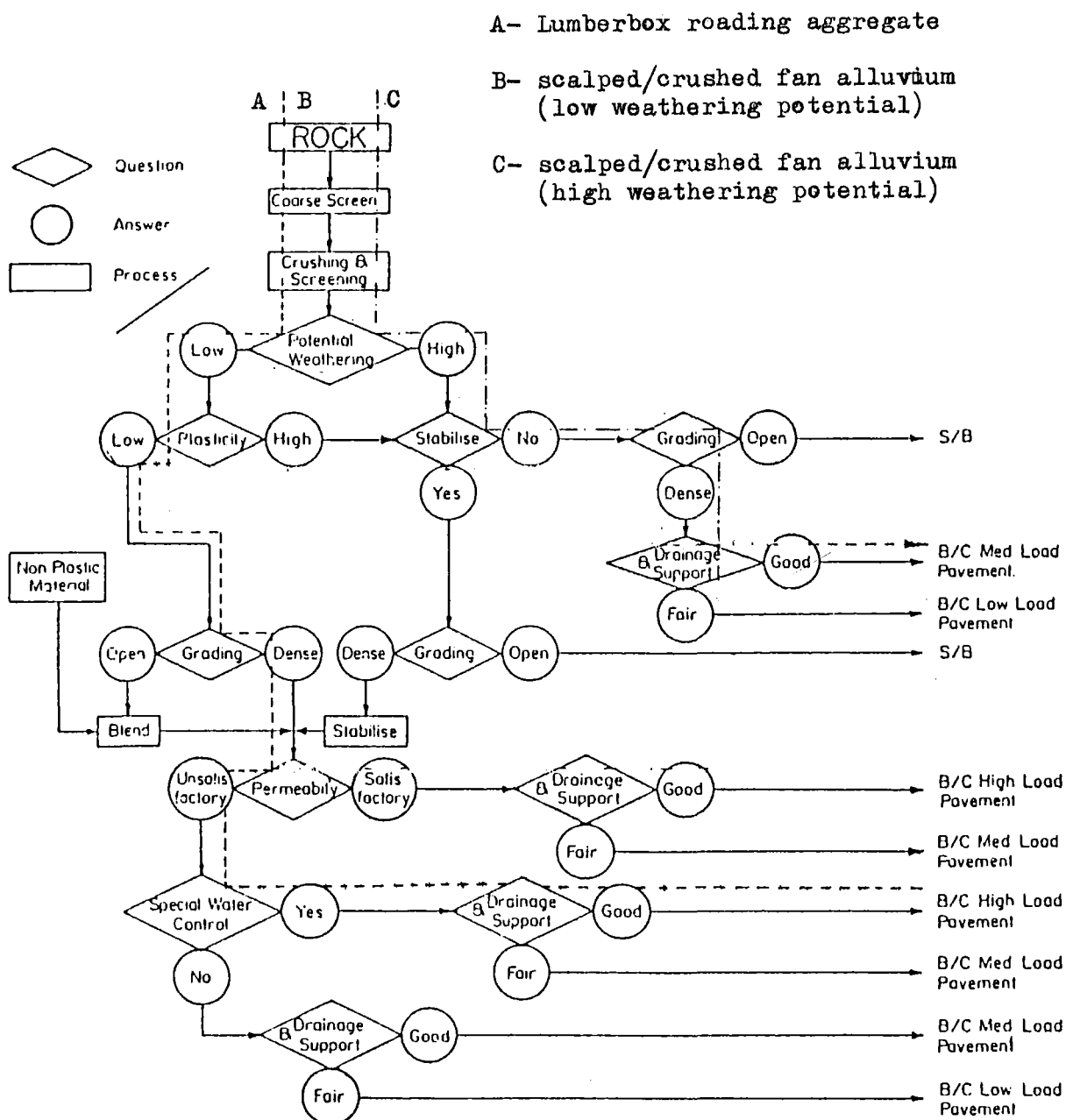
Bartley et al (1986) have used an aggregate selection chart to assess what type of loading the Lumberbox roding aggregate is suitable for. The Aggregate Selection Chart (Fig. 5.17) was proposed by Bartley, and later modified by Brennan and Van Barneveld (1985), indicates that the Lumberbox roding aggregate is suitable for high pavement loadings (in excess of  $5 \times 10^5$  EDA). The following characteristics were used by Bartley et al (1986) to define the loading:

- (a) weathering potential - low;
- (b) plasticity - low;
- (c) stabilization - none;
- (d) grading - dense;
- (e) drainage and support - good;

Geotechnical Tests	Fan alluvium scalped/crushed	Lumberbox scalped/crushed	M/4
Weathering Resistance	CB	BA	AA, BB, AC, BA, BB, CA
Crushing Resistance	140kN	190 kN	> 130. kN
Sand Equivalent	55	22	40
"n" values	0.55	0.52	0.4 - 0.60
Los Angeles Abrasion	40%	22 - 29%	NA
Clay index	1.05	1.5	NA
Plasticity Index	NP	NP	NA

NP - non plastic  
NA - not applicable

Table 5.16 Comparison of scalped/crushed fan alluvium, Lumberbox roading aggregate and M/4 quality roading aggregate.



## NOTES

S/B.... Subbase. B/C.... Basecourse  
 Low load pavement  $< 10^4$  E.D.A.  
 Med. load pavement  $10^4 - 5 \times 10^4$  E.D.A.  
 High load pavement  $> 5 \times 10^4$  E.D.A.  
 E.D.A. means 80 kN equiv. design axle  
 Dense grading -  $n < 0.5$

Permeability-Consider together with drainage and environment

Support Characteristics - Settlement  
 - Permeability  
 - Variability  
 - Bearing Capacity  
 - Moisture Sensitivity

## PLASTICITY OF FINES

Low Activity -  $< 10\%$  passing  $425 \mu\text{m}$   
 or  $SE > 40$   
 or  $SE > 20$  &  $CI < 3$   
 High Activity -  $> 10\%$  passing  $425 \mu\text{m}$   
 and  $SE < 30$   
 and  $CI > 5$

Drainage Characteristics - Shoulders  
 - Side Water Channels  
 - Kerbs  
 - Subsurface Drains  
 - Surfacing

Table 5.17 Aggregate selection chart (after Brennan and Van Barneveld, 1985).

(f) permeability - not known but assume "unsatisfactory"; and

(g) special water control - yes

"Special water control" means that all surface water should be shed quickly from the pavement to the side drains (Bartley et al 1986).

Test results of the scalped/crushed alluvial fan aggregate suggests a similar quality to the Lumberbox roading aggregate, but the fan alluvium may have a slightly higher weathering potential (ie. quality index of CB). When using similar conditions to the Lumberbox aggregate (Bartley 1986), but with a high weathering potential the aggregate selection chart indicates that under these conditions the roading aggregate should be suitable for medium pavement loads ( $10^4$ - $5 \times 10^5$  EDA) (Table 5.17).

Assuming a low weathering potential, for the scalped/crushed aggregate, and conditions similar to the Lumberbox selection chart, the alluvial fan roading aggregate under these conditions should be suitable for high pavement loadings (in excess of  $5 \times 10^5$  EDA). (Table 5.17)

### 5.12.3 Kame Terrace Roding Aggregate Quality

A crushing trial was not carried out on kame terrace aggregate, however with the information obtained from the lithological analysis of the kame terrace aggregate, and from geotechnical results of the crushed alluvial fan aggregate, the quality of roading aggregate produced from the kame terrace aggregate may be inferred.

The coarse aggregate fraction ( $>4.75\text{mm}$ ) has a higher greywacke content than the alluvial fan (Table 5.10), therefore it is envisaged that the kame terrace roading aggregate

will have a higher quality crushing resistance, weathering resistance and Los Angeles abrasion values. The estimated crushing resistance value is 180kN, the estimated weathering resistance index is BA, and the estimated Los Angeles abrasion value less than 40%.

The gradings demonstrate that kame terrace aggregate is variable and contains more fines than the alluvial fan aggregate, suggesting that the kame terrace aggregate will also require scalping during production. The additional fines are envisaged to produce sub-M/4 standard sand equivalent values. However, plasticity and clay index results of kame terrace sample 6B indicate that kame terrace fines have similar properties and mineralogy to the alluvial fan fines, ie. non-plastic with little or no smectites.

Kame terrace aggregate is also envisaged to be capable of producing roading aggregate of similar quality to roading aggregate produced at the Lumberbox, and capable of producing NRB M/4 with the exception of the sand equivalent requirement.

#### 5.12 SYNTHESIS AND RECOMMENDATIONS.

Test results have indicated the scalping will be required during production of roading aggregate from alluvial fan and kame terrace aggregate and if the -19mm fraction is scalped out, an average of  $53\% \pm 16\%$  of the aggregate will be removed. Scalping will enable a M/4 grading to be obtained and also may increase the sand equivalent values. The scalped/crushed alluvial fan roading aggregate is of similar quality to roading aggregate produced at the Lumberbox quarry



(ie. the best quality roading aggregate within the Wakatipu Basin), and is expected to be capable of meeting NRB M/4 specifications, with the exception of the sand equivalent value.

Considering the quality roading aggregate shortage within the Wakatipu Basin and the envisaged roading aggregate quality of the proposed quarry, it is recommended that an aggregate quarry be opened on the proposed Queenstown-Lakes District Council site.

Sand equivalent values of glacial derived deposits of the Wakatipu Basin are known to be sub-M/4. However, test results of the kame and alluvial fines, and the Lumberbox Test Sections indicate that the sub-M/4 sand equivalent values do not affect the performance of the roading aggregate. Therefore, it is recommended that the Council apply for an M/5 variant, reflecting lower sand equivalent values at the kame terrace source area ie. proposed Queenstown-Lakes District Council aggregate quarry.

## CHAPTER SIX

## SUMMARY AND CONCLUSIONS

## 6.1 GEOLOGICAL SETTING

Within the Wakatipu Catchment two types of basement rocks outcrop, Otago Schist and Caples Group. Rocks of the Caples Group outcrop on the north west side of Lake Wakatipu, and can generally be described as dominantly greywackes and argillites of late Permian to early Triassic age. Otago Schist can generally be described as quartzofeldspathic schists of the Chlorite metamorphic zone, and are of similar age. Late Quaternary deposits provide the Wakatipu Basin with roading aggregate sources. Three glacial (Otiran) and three post-glacial (Aranuian) deposits have been identified as potential aggregate sources, and are as follows:-

<u>Glacial</u> (Otiran)	<u>Post-Glacial</u> (Aranuian)
(a) Otiran alluvial fans	(a) Fan-delta complex;
(b) Kame terraces; and	(b) Deltas; and
(c) Outwash surfaces.	(c) Fan alluvium.

## 6.2 EXISTING ROADING AGGREGATE RESOURCES.

Eight aggregate quarries intermittently produce roading aggregate within the Wakatipu Basin, the Queenstown-Lakes

District Council has also been granted six gravel licences from which roading aggregate is produced. The existing aggregate quarries and the deposit they expose include:

- (a) Lumberbox - fan-delta complex;
- (b) Two Mile - fan-delta complex;
- (c) Mt Cook Group - kame terraces;
- (e) Northern Southland Transport - delta;
- (f) Farry - delta;
- (g) Twelve Mile - delta;
- (h) Twenty Five Mile - delta; and
- (i) Arthurs Point - delta.

Existing aggregate sources can generally be divided into two major groups; 1) schist-derived aggregate, and 2) schist and greywacke-derived aggregate. Schist-derived aggregates usually fail to meet the M/4 crushing resistance requirement of 130kN, with the exception of the Twelve Mile aggregate which has occasionally produced crushing resistance values of 130-140kN. Aggregates with more than 10% greywacke and schist meet the required crushing resistance value, but fail to meet the sand equivalent requirement.

Limited test results from the Farry and Two Mile quarries suggest that they may be capable of producing NRB M/4 quality aggregate. However, a complete M/4 testing programme has not been carried out on either roading aggregate, and both quarries have limited supplies of aggregate which would not be sufficient to meet future Queenstown-Lakes District Council roading aggregate requirements.

The Lumberbox quarry is the major producer of quality roading aggregate within the Wakatipu Basin. Aggregate from the quarry is glacial-derived, consisting of mixed schist and greywacke. The roading aggregate fails to comply with the M/4

sand equivalent requirement, however the Wakatipu Test Section and local experience with the material has demonstrated that the low sand equivalent values do not affect the performance of the roading aggregate.

### 6.3 AGGREGATE SURVEY

Four potential source areas have been identified between the geographical limits of the Lumberbox and Twelve Mile quarries, as follows:-

(a) Kame terraces on the lower westerly slopes of The Remarkables;

(b) Twelve Mile +45m delta;

(c) Alternative Twelve Mile delta; and

(d) Arthurs Point outwash surface.

The Queenstown-Lakes District Council initiated further investigations of the kame terrace and Twelve Mile +45m delta source areas.

Site investigations of the kame terrace source area included engineering geological mapping, test pit excavation and logging, sampling, and a crushing trial. Within the source area, till, kame terrace, delta and fan alluvium deposits have been identified. Potential kame terrace and fan alluvium aggregates consist of mixed schist and greywacke, which can be described as sandy fine to coarse gravel with some silt. Test pits excavated at the kame terrace source area suggest at least 900000m<sup>3</sup> of insitu kame terrace and alluvial fan aggregate is available in the resource.

Based on information provided by the author concerning quality and quantity of the kame terrace source area aggregate, the Queenstown-Lakes District Council decided to

develop an aggregate quarry at the site. The Queenstown-Lakes District Council received planning approval, subject to ten conditions, to quarry the kame terrace source area for roading aggregate.

Site investigation of the Twelve Mile source area included engineering geological mapping and the collection of one channel sample. A Mining or Prospecting licence was not granted for the source area and no further investigations could take place. The resource is estimated to be more than 400000m<sup>3</sup> of insitu aggregate. Roding aggregate produced from the schistose delta aggregate is predicted to have similar geotechnical properties to roading aggregate produced at the existing Twelve Mile and Farry quarries.

Seven potential deltaic source areas which consist of schist, and mixed schist and greywacke derived aggregates have been identified along the Queenstown-Glenorchy, Kinlock-Glenorchy and Greenstone Station Roads.

#### 6.4 GEOTECHNICAL TESTING

##### 6.4.1 Twelve Mile Delta

Limited testing of the Twelve Mile +45m delta source area confirms that the aggregate is capable of producing roading aggregate suitable for use as a basecourse, and is of similar quality to the existing Twelve Mile quarry.

##### 6.4.2 Kame Terrace Source Area.

A geotechnical testing programme was carried out on crushed fan alluvium from the kame terrace source area. The results indicate that the roading aggregate does not comply

with the NRB M/4 specification. The weather resistance results narrowly miss the M/4 standard with a Quality Index of CB, and further testing is required to establish if the crushed fan alluvium consistently fails the weather resistance test. The crushed fan alluvium does not meet the M/4 grading requirement, but with quality control during production an M/4 grading would be obtainable. However, crushed fan alluvium is comparable with Lumberbox aggregate and is suitable for use as a basecourse.

Like other glacial-derived deposits within the Wakatipu Basin (eg. Lumberbox), roading aggregate produced at the Kame terrace source area may have problems complying with the NRB M/4 sand equivalent requirement. Test results suggest that the fines fraction is predominantly of silt size, non-plastic and contains little or no smectite clays, therefore the low sand equivalent values are not expected to produce any stability problems within the pavement.

Particle size distributions of the roading aggregate indicate that scalping will be required during production to achieve an M/4 grading. If a scalping size of -19mm is used, particle size distributions of the kame terrace and alluvial fan aggregates infer that an average of  $53\% \pm 16\%$  of the aggregate will be scalped out.

Kame terrace aggregate has a higher greywacke and silt content than the fan alluvium aggregate therefore, roading aggregate produced from the kame terrace aggregate is expected to have a higher crushing resistance and weathering resistance, but a lower sand equivalent value.

## 6.5 PRINCIPAL CONCLUSIONS.

1) Six Late Quaternary aggregate sources are recognised within the Wakatipu Basin, of these three are glacial and three are post-glacial and are as follows:-

Glacial (Otiran)

- (a) Otiran alluvial fans
- (b) Kame terraces; and
- (c) Outwash surfaces.

Post-Glacial (Aranuian)

- (a) Fan-delta complex;
- (b) Deltas; and
- (c) Fan alluvium.

2) Mixed schist and greywacke aggregate produce the highest quality roading aggregate within the Wakatipu Basin, producing crushing resistance values which range from 180 to 190kN and sand equivalent values which range from 18 to 35.

3) Limited geotechnical tests indicate that the Twelve Mile +45m delta aggregate does not comply with the NRB M/4 specifications, but is of similar quality to the existing Twelve Mile quarry, and is therefore suitable for basecourse production.

4) Test pits excavated at the kame terrace source area suggest that at least 900000m<sup>3</sup> of insitu kame terrace and fan alluvium aggregate is available within the resource.

5) Geotechnical testing programmes carried out on crushed fan alluvium from the kame terrace source area identified the roading aggregate as sub-M/4 standard, but as comparable with the highest quality aggregate of the Wakatipu Basin produced at the Lumberbox.

6) It is presumed that scalping at the proposed Queen-

stown-Lakes District Council quarry (ie. kame terrace source area) will be required to produce a NRB M/4 AP40 grading, if 19mm is used as a scalping size an average of  $53\% \pm 16\%$  will be scalped out.

7) Based on information supplied by the author the Queenstown-Lakes District Council decided to develop a roading aggregate quarry within the kame terrace source area. On the 4th of June 1987, Queenstown-Lakes District Council received planning approval to quarry the kame terrace source area for roading aggregate.

#### 6.6 RECOMMENDATIONS.

1) It is recommended that an aggregate quarry be opened at the kame terrace source area, in both the kame terraces and alluvial fan deposits.

2) Experimentation with a scalping size less than 19mm is recommended, with the objective of maximizing the resource.

3) It is recommended that Council apply for an M/5 variant, reflecting the lower sand equivalence at the kame terrace source area ie. proposed Queenstown-Lakes District Council aggregate quarry.



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## APPENDIX ONE

### NRB M/4 SPECIFICATIONS

SPECIFICATION FOR CRUSHED BASECOURSE AGGREGATE

1. SCOPE

This specification sets out requirements for crushed basecourse aggregate for use on state highways and other heavily trafficked roadways.

2. TESTING

2.1 Tests to check compliance with this specification shall be carried out on representative samples of the aggregate selected from bin, stockpile or truck. The representative sample shall weigh at least 30 kilograms.

2.2 Unless otherwise stated or implied below, the requirements shall be met by every representative sample tested.

3. PROPORTION OF BROKEN ROCK

In each of the three aggregate fractions between the 37.5 mm and 4.75 mm sieves not less than 70% by weight shall have two or more broken faces.

4. CRUSHING RESISTANCE

4.1 The crushing resistance shall not be less than 130 kN when the aggregate is tested according to NZS 3111:1980 Section 14 'Method for determining crushing resistance of coarse aggregate'.

4.2 An aggregate will be considered to have met the requirement if the sample produces less than 10 percent of fines when loaded so that the specified peak load is reached in 10 minutes. In this case the test shall follow the standard method in all other respects. If the aggregate passes the test it shall be reported as having a crushing resistance 'greater than (the load specified)'.

5. WEATHERING RESISTANCE

The aggregate shall have a quality index of AA, AB, AC, BA, BB or CA when tested according to NZS 3111:1980 Section 15, 'Method for determining weathering resistance of coarse aggregate'.

6. SAND EQUIVALENT

The sand equivalent shall not be less than 40 when the aggregate is tested according to NZS 4402 Part 1:1980 Test 7 'Determination of the sand equivalent'.

## 7. GRADING

### 7.1 Grading Limits

When tested according to NZS 4402 Part 1:1980 Test 9(B) 'Suosidiary method by dry sieving', or Test 9(A) 'Standard method by wet sieving' where aggregates contain clay or other fine material causing aggregation of the particles, the grading of the aggregate shall fall within the respective envelope defined in Table A below. Table A defines gradings for M/4 AP40 and M/4 AP20.

TABLE A GRADING ENVELOPE	TEST SIEVE APERTURE	PERCENTAGE PASSING	
		AP40	AP20
	37.5 mm	100	
	19.0 mm	66 - 81	100
	9.5 mm	43 - 57	55 - 75
	4.75 mm	28 - 43	33 - 55
	2.36 mm	19 - 33	22 - 42
	1.18 mm	12 - 25	14 - 31
	600 µm	7 - 19	8 - 23
	300 µm	3 - 14	5 - 16
	150 µm	10 max	12 max
	75 µm	7 max	3 max

### 7.2 Grading Shape Control

The weight of material in each fraction shall lie within the limits defined in Table B below.

TABLE B GRADING SHAPE CONTROL	FRACTIONS	PERCENTAGE OF MATERIAL WITHIN THE GIVEN FRACTION	
		AP40	AP20
	19.0 - 4.75 mm	28 - 48	-
	9.5 - 2.36 mm	14 - 34	20 - 45
	4.75 - 1.18 mm	7 - 27	9 - 34
	2.36 mm - 600 µm	6 - 22	6 - 25
	1.18 mm - 300 µm	5 - 19	3 - 21
	600 µm - 150 µm	2 - 14	2 - 17

## 8. BASIS OF MEASUREMENT AND PAYMENT

When the contract item is for the supply of aggregate only payment will be made on the quantity of aggregate meeting this specification and delivered to the delivery point in the manner specified. The

quantity of aggregate shall be measured loose in the delivery trucks at the delivery point and all loads shall be level with the top edges of the tray of the truck. Truck capacities will be measured by the engineer and truncated to the next lower half cubic metre.

A tallyman's delivery receipt does not imply that the aggregate is acceptable and all aggregate that does not meet this specification shall be removed at the contractor's expense.

Measurement of the aggregate in accordance with NRB G/2, Conditions for supply of aggregate by weight, may be considered by the engineer at the request of the Contractor.

When the supply of aggregate is included with the construction of basecourse as one item under the contract, payment shall be made as detailed in National Roads Board Specification 8/2.

## APPENDIX TWO

### ENGINEERING GEOLOGICAL DESCRIPTIONS OF REMARKABLES FIELD AREA



A2 FIELD DESCRIPTIONS OF THE REMARKABLES STATION FIELD  
AREA

A2.1 Otago Schist.

SCHIST

Dark greyish brown, unweathered, foliated, high strength SCHIST. Well developed foliation dips SW. Joints are moderately widely spaced (OTAGO SCHIST Textural Zone IV)

A2.2 Otiran Alluvial Fan.

GRAVEL Light brownish grey, unweathered, massive, fine to coarse GRAVEL with some sand and rare cobbles and silt (GW/GP);

-loose to compact; dry; poorly to well graded; gravel, subrounded to subangular, TZ III & IV schist; sand, fine to coarse; silt, non-plastic; occasionally silty fine sand lenses.

A2.3 Kame Terraces.

SANDY GRAVEL

Light greenish grey, unweathered, massive to faintly bedded, SANDY fine to coarse GRAVEL with some silt and rare cobbles (GM/GW)

-compact to loose; moist, poorly to well graded; gravel, rounded to sub angular, TZ II, III & IV schist, quartz and greywacke (10-30%); sand, fine to coarse; silt, non plastic; occasional silt/sand lenses [CAMP HILL FORMATION].

#### A2.4 Ablation Till.

##### SAND/SILY/GRAVEL

Light grey, unweathered, massive, SAND/SILT/GRAVEL;  
(GM)

-compact; moist; poorly to well graded; gravel, fine to coarse, rounded to subangular, TZ II, III and IV, quartz, greywacke (30-40%); silt, non plastic; sand, fine to coarse;

#### A2.5 Fan Delta Complexes.

The grain size of the fan-delta complexes varies from a Gravely/Silty Sand in a distal location to a Sandy Gravel in a proximal location. A general field description of the proximal environment fan-delta complex aggregate (part of complex suitable for aggregate production) is as follows;

##### SANDY GRAVEL

Light grey, unweathered, bedded, SANDY fine to medium GRAVEL (GP/GW).

-loose to compact ; moist to dry; well to poorly graded; bedded, sub-horizontal to gently inclined, thin to thick; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (10-30%); sand, fine to coarse; with occasional gravely sand lenses and gravel lenses.

#### A2.6 Delta.

##### SANDY GRAVEL

Light grey, unweathered, current bedded, SANDY fine to medium GRAVEL (GP/GW);

-loose to compact ; moist to dry; well to poorly graded; bedded, sub-horizontal to gently inclined, thin to thick; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (10-30%); sand, fine to coarse; occa-

sional sand lenses and gravel lenses.

#### A2.7 Fan Alluvium.

##### SANDY GRAVEL

Light grey, unweathered, bedded, SANDY fine to coarse GRAVEL (GP/GW).

-loose to compact ; moist to dry; well to poorly graded; bedded, sub-horizontal to gently inclined, thin to thick; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (5-20%); sand, fine to coarse; occasional sand lenses and gravel lenses.

#### 2.8 Lake Sediment.

##### CLAYEY/SILTY SAND

Light grey, unweathered, massive to laminated, CLAYEY/SILTY SAND (ML)

-soft to firm; moist; sand, fine to coarse; silt and clay semi to non plastic; with occasional fine gravel lenses.

### APPENDIX THREE

#### PRELIMINARY REPORT ON THE WAKATIPU AGGREGATE SURVEY INVESTIGATIONS TO DATE

4041/22/13313 (6-4)  
17 June 1986

CONFIDENTIAL

The County Clerk  
Lake County Council  
PO Box 25  
QUEENSTOWN

Dear Sir

PRELIMINARY REPORT ON THE WAKATIPU AGGREGATE SURVEY  
INVESTIGATIONS TO DATE

1.0 Scope of Report

The scope of the preliminary report is to:

- (i) Establish roading aggregate source areas in the Queenstown area between the Twelve Mile and Lumber Box gravel pits not presently used or identified;
- (ii) Give a visual description of the aggregate and the deposit source areas;
- (iii) Give a rough approximation of the minimum amount of aggregate present, using outcrops and visual means;
- (iv) Establish ease of access;
- (v) Establish owner and occupier (if other than the owner).

2.0 Roding Aggregate of the Queenstown Area

It is generally accepted that Shotover aggregate is substandard for most roading purposes, owing to a Crushing Resistance (NZS 3111:1980 Test 14) usually less than 100 kN. Therefore, we have restricted this survey to source areas which will contain a certain percentage of greywacky, in an attempt to find an aggregate with a suitable Crushing Resistance. However, if these greywacky rich aggregate sources prove to be unsuitable, further investigation of the easily accessible and renewable Shotover aggregate would be advisable.

After three days field work in May 1986 two aggregate source areas have been denoted (see appendix I);

## 2.1 Twelve Mile Creek Mouth

In this source area two aggregate deposits are present:

### 2.1.1 Riverbed Aggregate

### 2.1.2 + 45 m Lake Level Deltic Aggregate

### 2.1.1 Riverbed Aggregate

The aggregate deposit is situated on the true left bank of the Twelve Mile Creek mouth.

A visual description of the aggregate follows,

#### SANDY GRAVEL

Light grey, unweathered, massive to laminated, SANDY fine to coarse GRAVEL with some cobbles, well to poorly graded; compact to loose; gravel, rounded to subangular, textural zone III and IV schist, quartz, greywacke; sand, coarse to fine; laminated with fines rich to fines poor lenses.

The riverbed aggregate deposit has a variable amount of recent alluvium overlying the above described aggregate. This recent alluvium is a COBBLY GRAVEL with some sand and is usually about 1 metre thick. The deposit appears to be laterally and lithologically consistent in nature. The aggregate deposit has a similar depositional environment and visual description to the present Twelve Mile aggregate pit. Therefore, the Riverbed aggregate is expected to have similar properties to the Twelve Mile aggregate.

On the true left bank of the Twelve Mile Creek lies approximately 70,000 m<sup>3</sup> of aggregate. The true right bank was not investigated, however the amount of aggregate is expected to be of similar, if not larger, amount than the true left bank.

Access to the aggregate deposit would not be a problem. A metal surfaced road extends from Glenorchy Road to the true left bank. The road would need upgrading if used for pit access.

This deposit is situated in the Twelve Mile Creek and therefore permission to remove gravel would be required from the Otago Catchment Board.

#### 2.1.2 +45 m Lake Level Delter Aggregate

The aggregate deposit is situated in the +45 m Lake Level Delter terrace on the true right bank of the Twelve Mile Creek Mouth.

The visual description of the aggregate is identical to the Riverbed aggregate (see 2.1.1). The deposit appears to be laterally and lithologically consistent in nature. The aggregate deposit is overlain by 0.5 m of overburden. A similar depositional environment to the Riverbed aggregate is also envisaged. Hence similar aggregate properties to the Riverbed aggregate and the present Twelve Mile aggregate is expected.

The amount of aggregate present in the deposit is estimated at being at least 200,000 m<sup>3</sup> and may be much larger than this estimate.

Access would be by the same means as mentioned in 2.1.1.

The owner of the land is the "Lands and Survey Department." The occupier is the "Mid Wakatipu Domain Board."

#### 2.2 Remarkables Road Kame Terraces

This source area lies on the Remarkables side of Boyd Road and extends south along S.H. 6 to the Mobil pumping station (see appendix I).

A visual description of the Kame terrace material is:

##### SANDY GRAVEL

Light grey, unweathered, massive to laminated, SANDY fine to coarse GRAVEL with some cobbles and boulders, loose to compact; well to poorly graded; gravel, rounded to subangular, textured zone II, III and IV schist, quartz and greywacke; sand, coarse to fine; occasionally laminated with fine poor lenses.

Kame terrace aggregate deposits are usually variable laterally and lithologically, this is attributable to their depositional environment and recent river activity eroding the terraces. Substantial Kame terraces are present in the above mentioned source area. These Kame terraces will extend south of the source area to the Lumber Box, however in this area they appear less evident. If the source area aggregate proves to be unsuitable, the area south of the source area to the Lumber Box should be investigated further. The Lumber Box is a similar Kame terrace deposit to the source area Kame terraces therefore the source area aggregate is expected to have similar properties to the Lumber Box aggregate.

Note that the Kame terrace source area material appears to have an overall higher greywacky content than the Twelve Mile Creek source area. This indicates that the Kame terrace material would have an overall higher Crushing Resistance (testing would be required to prove this). A testing programme of both source areas would have to be undertaken to establish which source area was the most efficient and effective aggregate to process and use for a roading aggregate.

Owing to the variable nature of Kame terraces the amount of aggregate present is hard to estimate. Two Kame terraces in the source area have been mined and used for roading aggregate on the Remarkables road. These mined areas are approximately 3 m deep x 2,500 m<sup>2</sup>. Therefore, approximately 15,000 m<sup>3</sup> of aggregate has been mined from the two Kame terraces. There are several Kame terraces in the source area therefore an approximation of at least 50,000 m<sup>3</sup> is given for the source area. This estimation may be larger, as in some areas the Kame terraces appear to be thicker. This is indicated by outcrops such as the Lumber Box and an outcrop on the Northern Southland Transport property where a dozer cut provides an outcrop which suggests the Kame terrace in that region to be greater than 20 m thick.

Access to the source area can be easily gained from Boyd Road, S.H. 6, Remarkables road and a metal surfaced road leading to a gravel pit on the Northern Southland Transport Holdings Limited property. The gravel in the pit on this property is not Kame terrace material and has an inferior greywacky content. This suggests an unsuitable Crushing Resistance, however testing would be required to prove this.

The owners and occupiers of the land are set out below.

- (i) Mee, Jean Elizabeth
- (ii) Boyd, Irvine
- (iii) The Mount Cook Group Ltd
- (iv) New, Ernest Norman and New, Lois Elaine
- (v) Northern Southland Transport Holdings Ltd
- (vi) Mobil Oil (NZ) Ltd
- (vii) Jardine, Dickson Stewart and Jardine, Andrew Glendinning
- (viii) Crown Lands and Survey Department (owner) Mount Cook Group Ltd (occupier).



3.0 Further Investigation

We trust this is sufficient for your present requirements, and await further instructions on investigations:

- (i) Cease investigations.
- (ii) To undertake a testing programme to establish which source area is the most efficient and effective aggregate to process.
- (iii) To prove the quality and quantity of the Councils preferred aggregate source area and/or deposit.

Quality of aggregate would be tested by completing

- (i) Crushing Resistance (NZS 3111:1980 Test 18);
- (ii) Sand Equivalent (NZS 3111:1980 Test 14) and
- (iii) Sieve Analysis (NZS 4402 Part 1:1980 Test 9a) on channel samples collected.

If the aggregate proved suitable, quantity of the aggregate could then be proved with the use of a backactor, further test samples would also be collected and tested.

We await your further instructions.

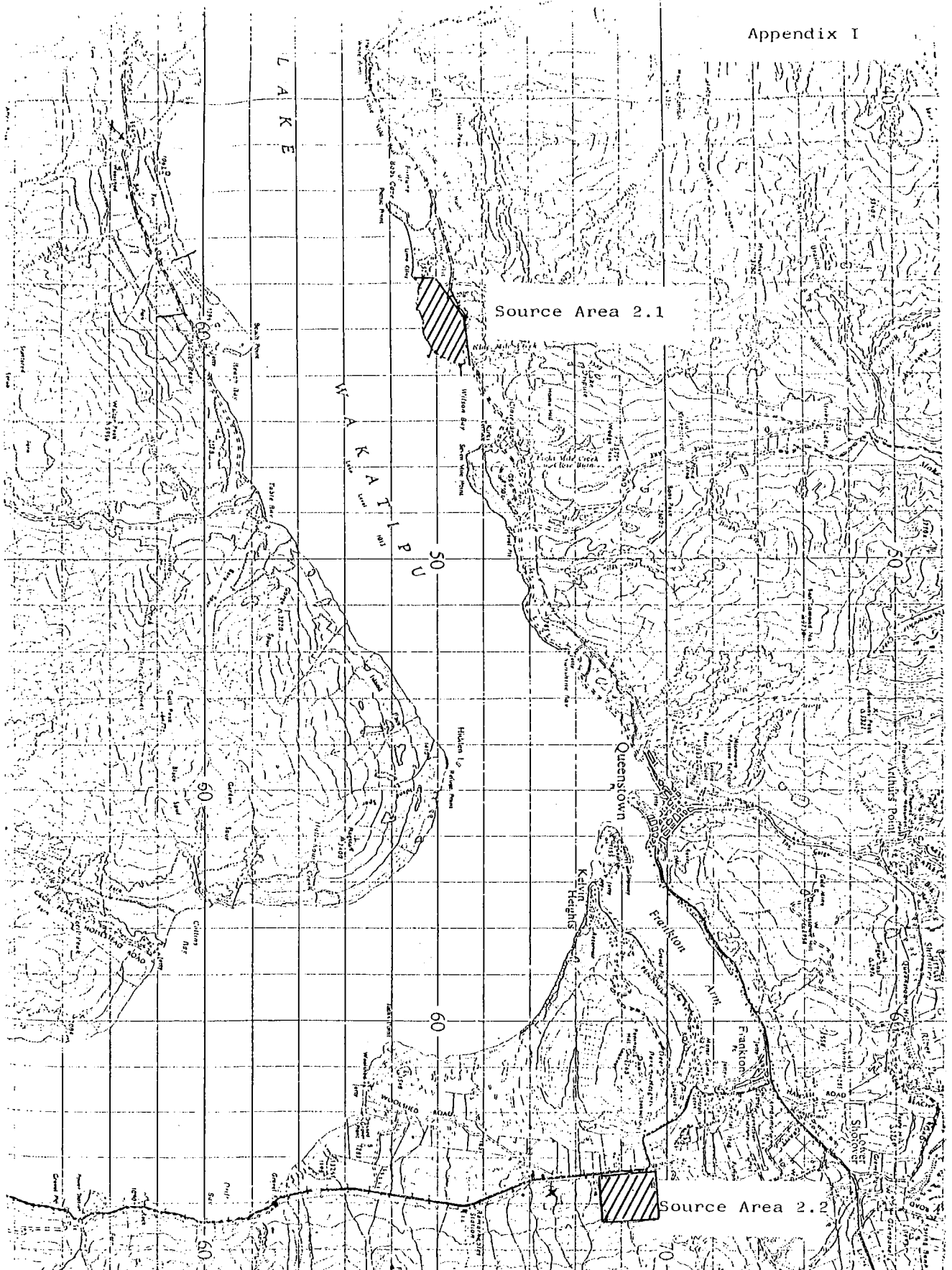
Yours faithfully  
DUFFILL WATTS & KING LTD



DIRECTOR

Encl Appendix I

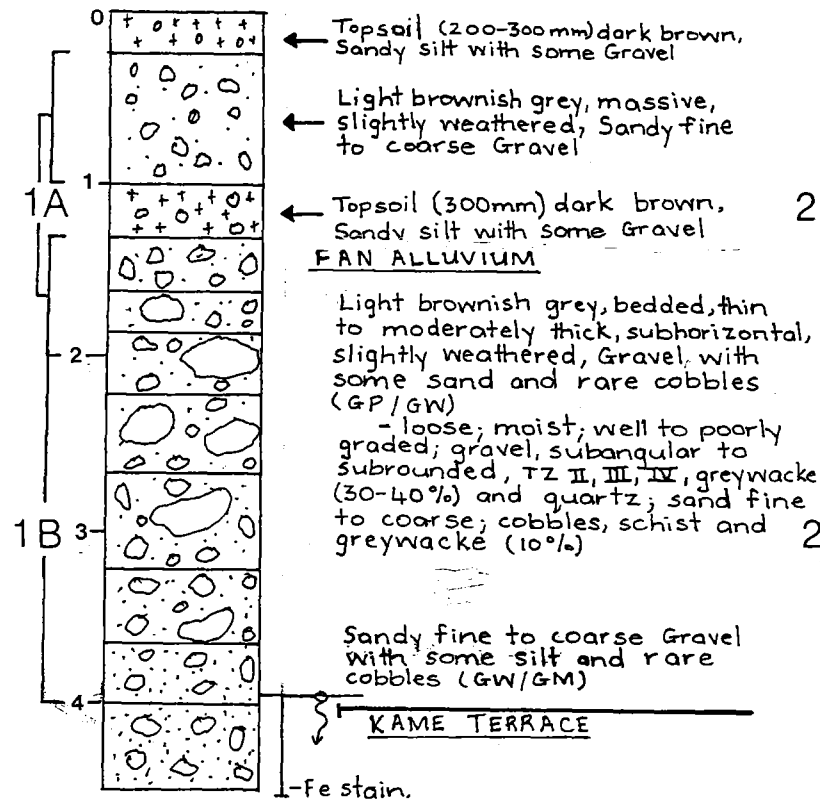
Appendix I



## APPENDIX FOUR

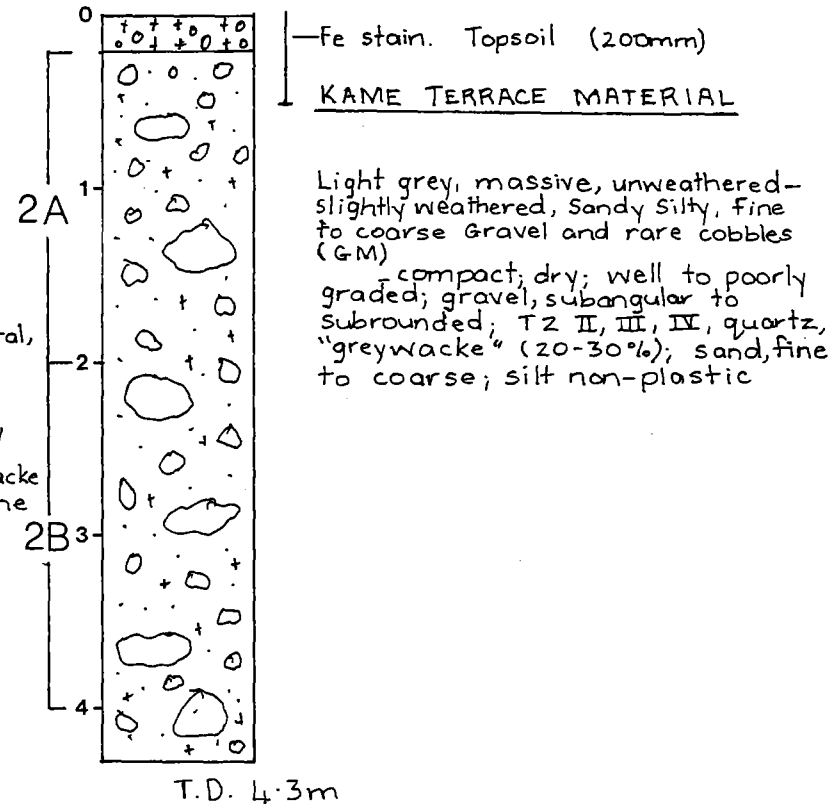
## TEST PIT LOGS OF KAME TERRACE SOURCE AREA

## TEST PIT ONE

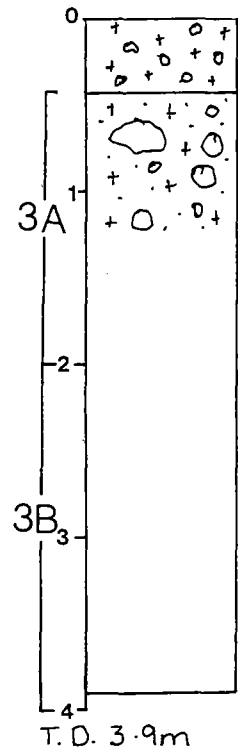


Light brownish orange (Fe stain), massive, slightly weathered, silty fine to coarse Gravel with some Sand (GM)  
- loose to compact; moist; poor to well graded; gravel subangular to subrounded, T2 II, III, IV, greywacke (20-30%), quartz; silt semi plastic; sand fine to coarse.

## TEST PIT TWO



### TEST PIT THREE

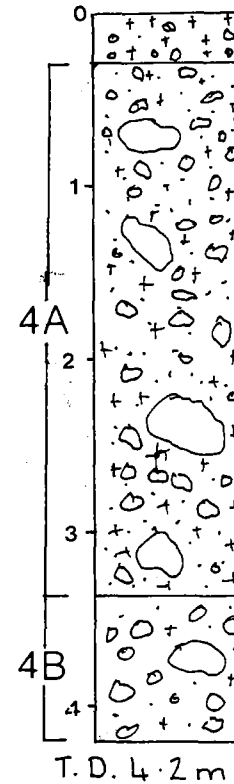


— Fe stain. Topsoil, light, mostly weathered, Gravely silt

#### KAME TERRACE MATERIAL

Light greenish grey, massive, slightly weathered, Sandy fine to coarse Gravel with rare silt and cobbles (GW/GP)  
- loose to compact; moist; well to poorly graded; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (20-30%); sand fine to coarse; occasional fine to coarse gravel lenses

### TEST PIT FOUR



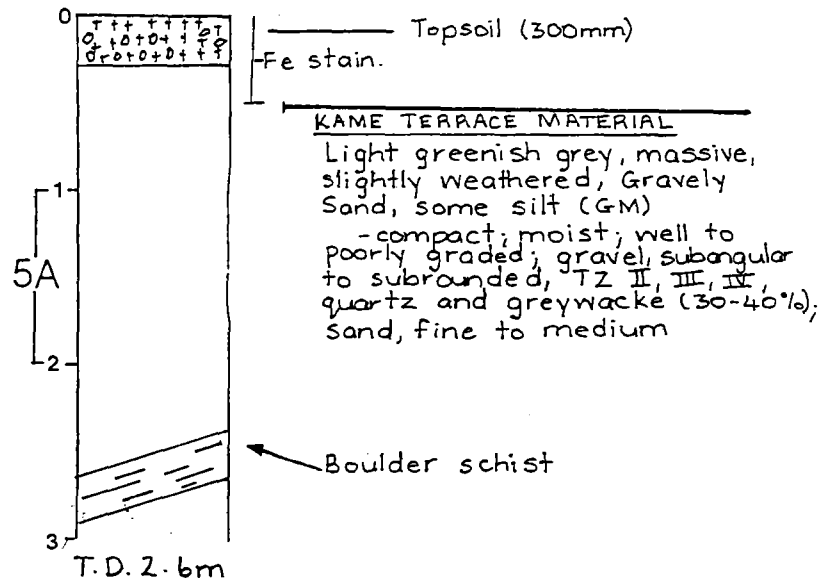
— Top soil (300mm)  
— Fe stain

#### KAME TERRACE MATERIAL

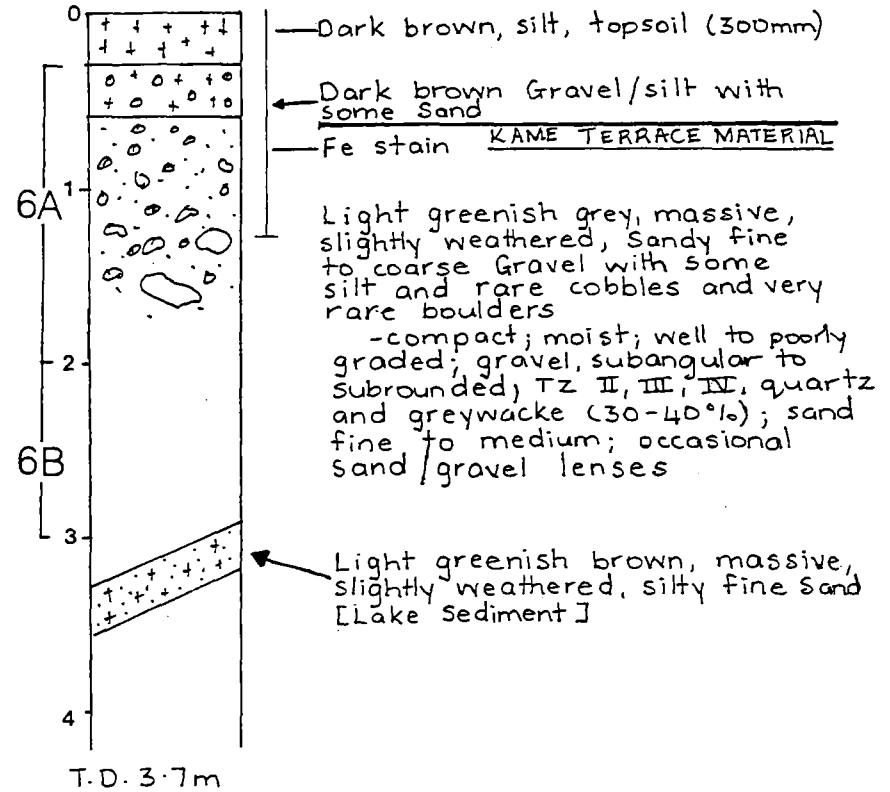
Light brownish grey, massive, slightly weathered, Sandy fine to coarse Gravel with some silt and rare cobbles and very rare boulders (GW/GM)  
- compact; moist; well to poorly graded; gravel, subangular to subrounded, TZ II, III, IV, quartz and greywacke (20-30%); sand, fine to coarse; silt non-plastic

— Light brownish grey, massive, slightly weathered, Sandy fine to coarse Gravel and rare silt (GW/GM)

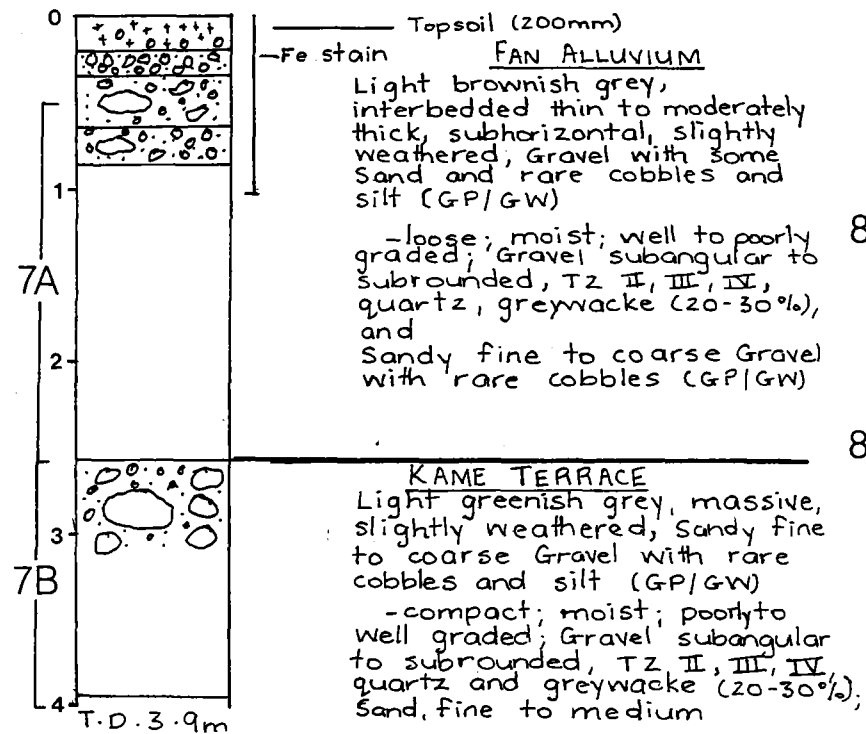
### TEST PIT FIVE



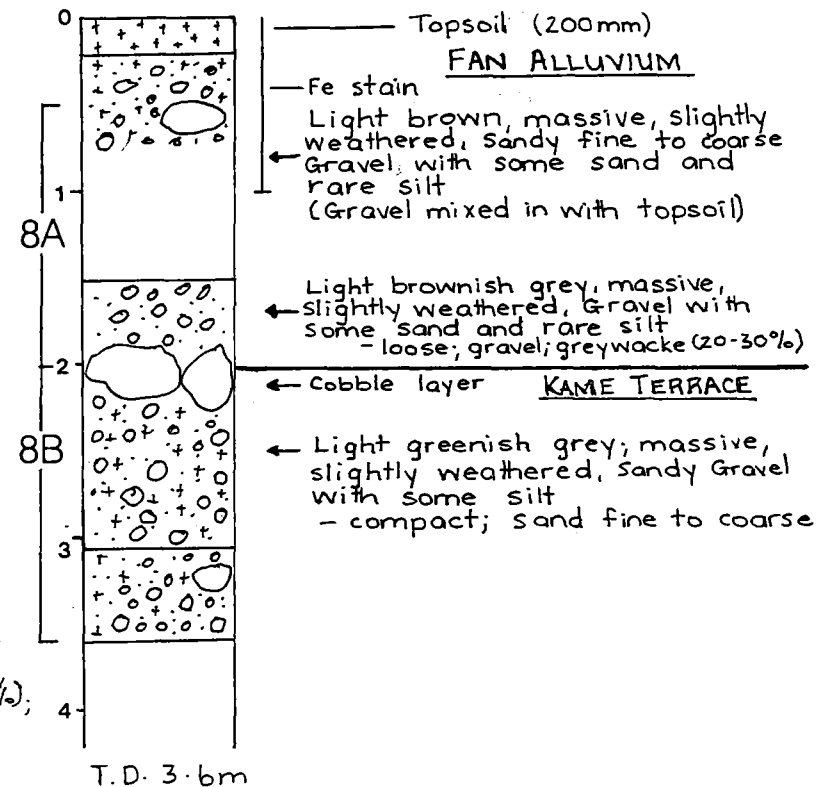
### TEST PIT SIX



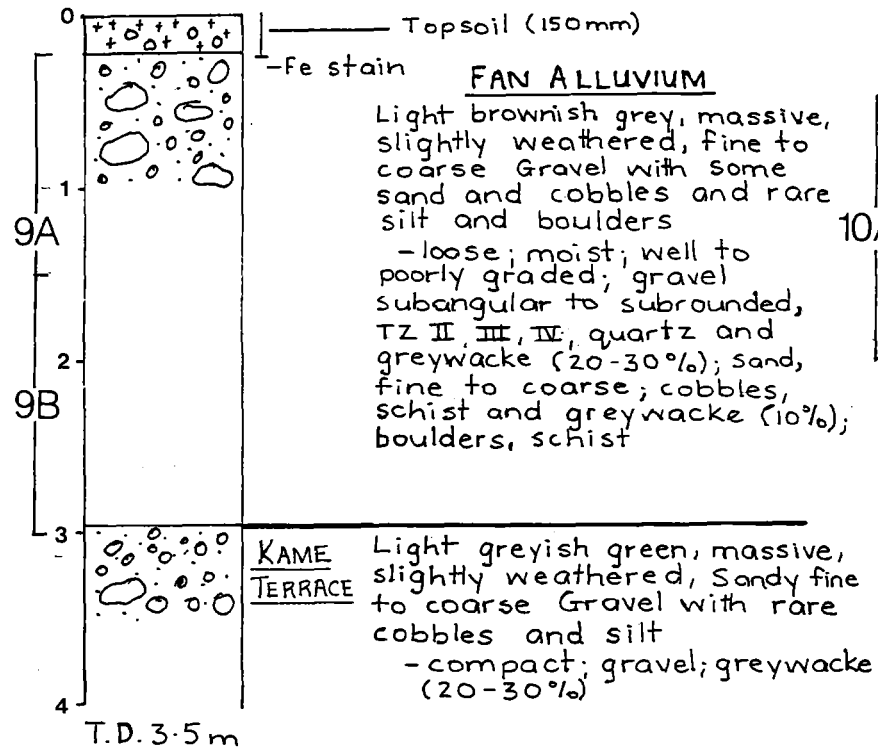
## TEST PIT SEVEN



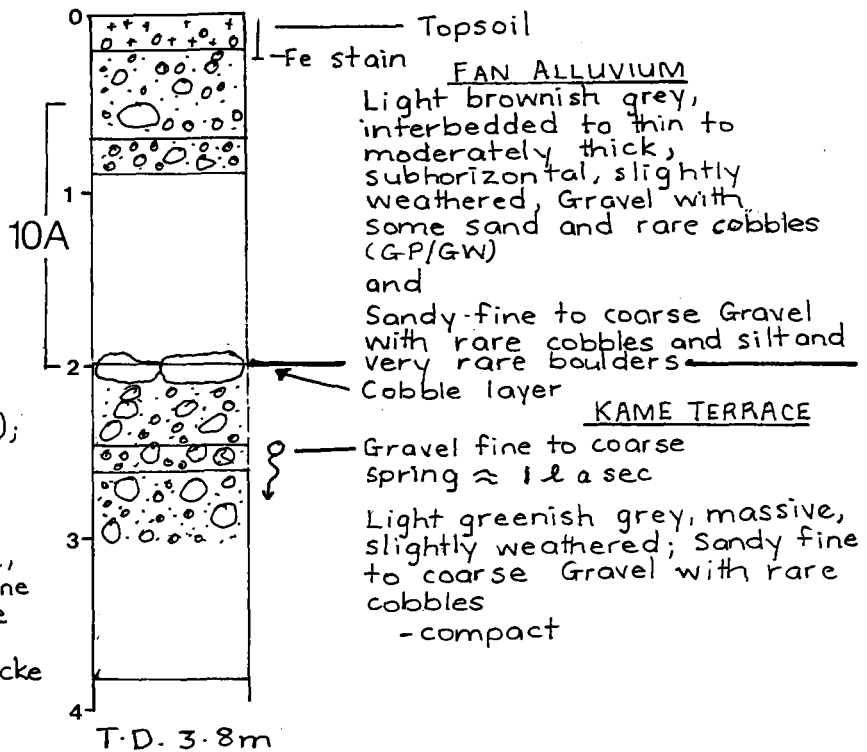
## TEST PIT EIGHT



## TEST PIT NINE

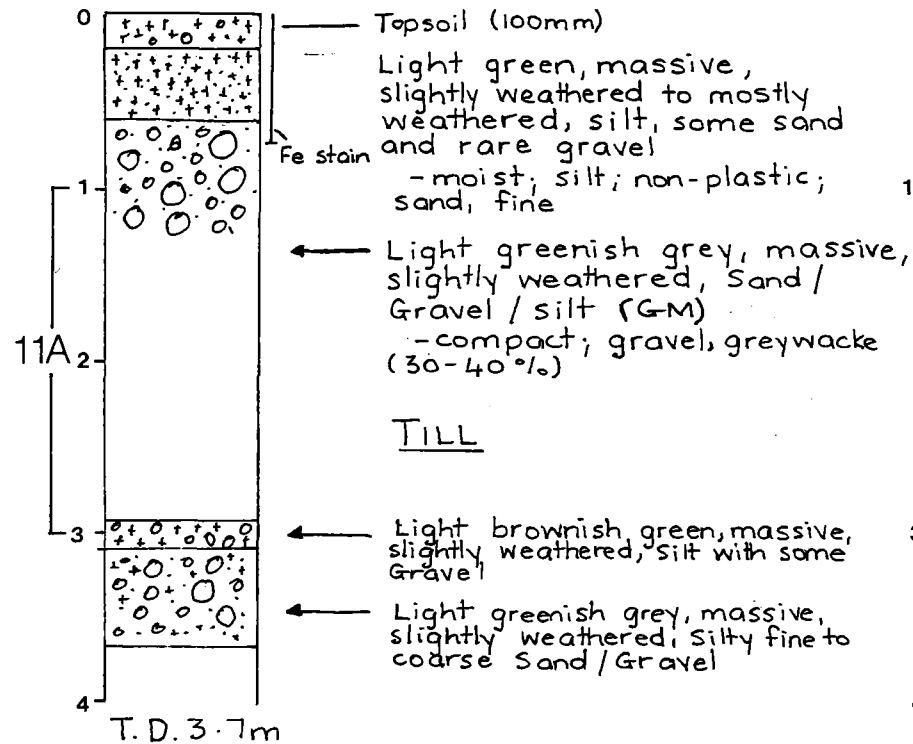


## TEST PIT TEN

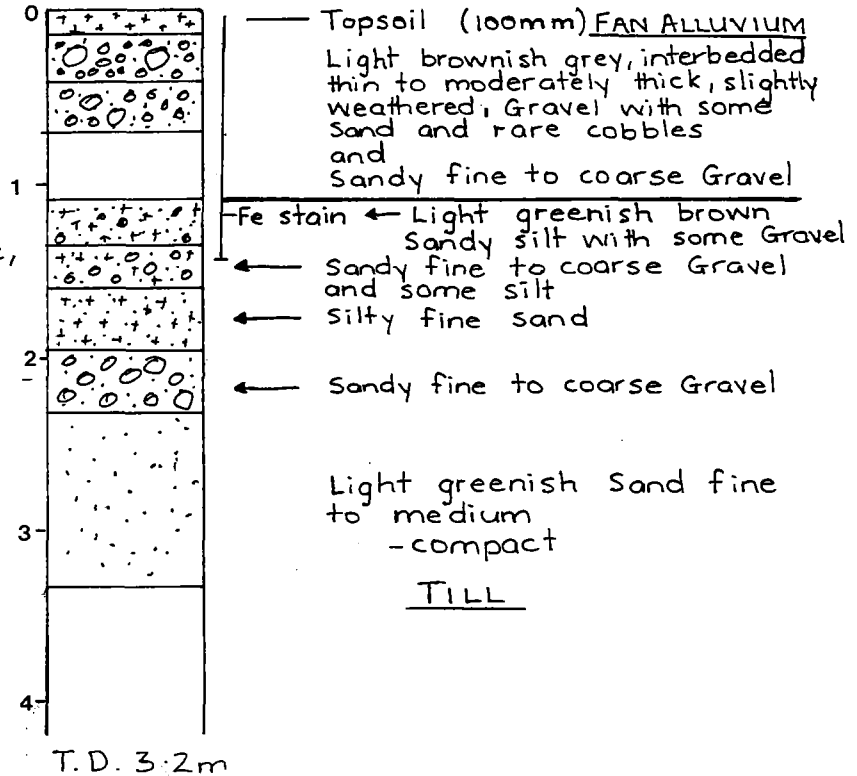




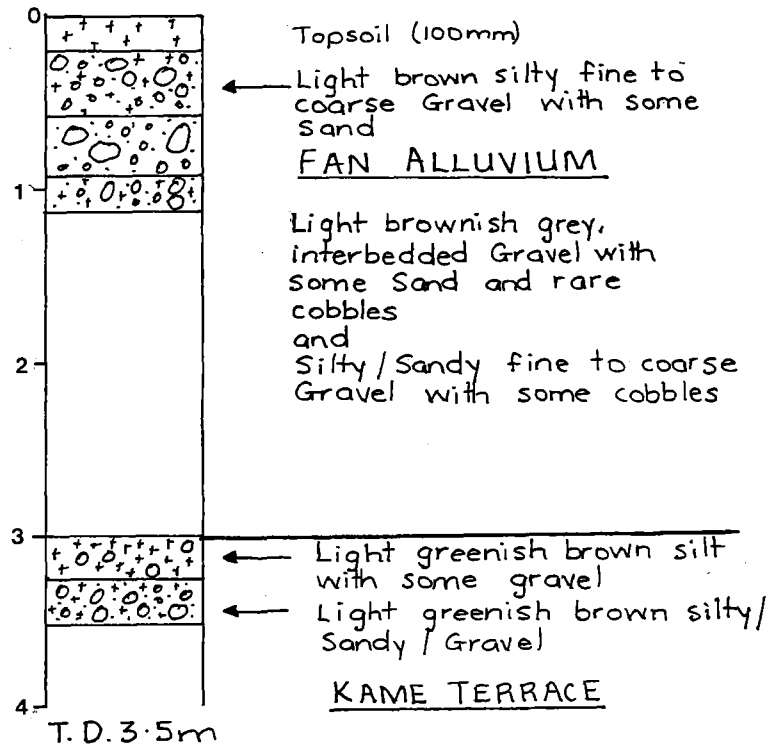
## TEST PIT ELEVEN



## TEST PIT TWELVE



# TEST PIT THIRTEEN



## APPENDIX FIVE

MANAGEMENT PLAN FOR PROPOSED QUEENSTOWN-LAKES DISTRICT  
COUNCIL QUARRY

QUEENSTOWN-LAKES DISTRICT COUNCIL

GRAVEL PIT OFF STATE HIGHWAY 6

MANAGEMENT PLAN

ACCESS

An access road would be constructed from State Highway 6 to the proposed quarry, on a line agreed upon by Mr and Mrs Jardine and the Council. An appropriate line would be from State Highway 6, extending towards the centre of the proposed quarry area, adjacent to an existing fence line, thereby minimising the effect on present farm layout.

The roadway would be fenced with a stock proof fence and gateways would be placed in convenient positions to allow stock and farm machinery thoroughfare.

Three small creeks are present in the proposed quarry area. The amount of water carried varies from dry to a steady flow after a heavy rainfall and during the snow melt. Culverts would be placed along the access road as required.

Access onto State Highway 6 would be located to ensure adequate visibility. The access roadway will intersect State Highway 6 at right angles and would be sealed from the edge of the seal of State Highway 6 to the road reserve boundary.

EXCAVATION METHOD

It has been agreed that at no times shall more than one area of land be used for the purposes of quarrying and that the area itself shall at all times be fenced with a stock proof fence.

It is anticipated that the overburden would be removed by bulldozer and the topsoil from the overburden stockpiled for later reinstatement.

Preliminary investigations show that material suitable for the production of roading aggregate is present to a depth of greater than 4m.

The material would be obtained by regrading the quarry area. Regrading would consist of excavating material to create a slope consistent with the surrounding landform. (approx 5 - 10 sloping towards State Highway 6).

Excavation would be completed by using cuts with near vertical bench heights of 3-4m. Loader and/or bulldozer would be used to excavate the material from the face.

Several naturally occurring Kame terraces are present within the proposed quarry area. These terraces would be utilized as buffer zones to minimise the visual impact of the quarry, from State Highway 6. This would be achieved by excavation proceeding on the eastern side of the Kame terraces.

It is envisaged that the first area to be excavated would be on the east boundary of the total area. Several hectares in this area lie east of a Kame terrace. Excavation would proceed from the eastern boundary of the proposed quarry area moving west until the edge of the terrace. The terrace edge would be left intact to act as a buffer zone. Excavation would proceed behind the terrace edge until the area was fully utilized. The terrace edge would then be excavated to a similar level and slope as the quarry area, thus allowing natural drainage to occur.

When a quarry area has been fully utilized, unused scalplings and overburden would be backfilled and shaped to create a gentle slope dipping towards State Highway 6. The stockpiled topsoil would be replaced and grass sown for the first growing season following.

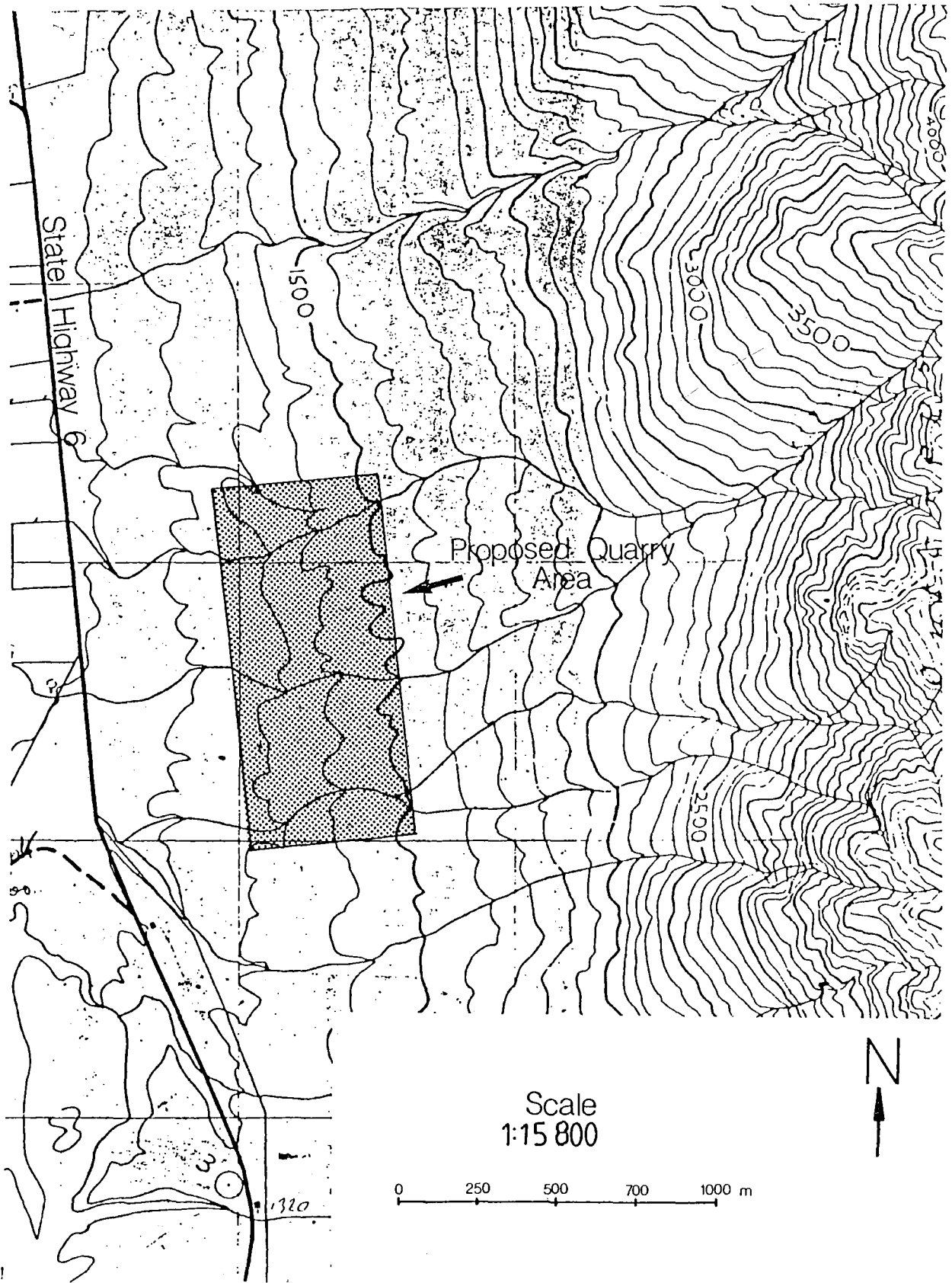
### 3. PRODUCTION

The plant used to produce the roading aggregate would be one of the mobile crushing plants that is active in the Queenstown area. It is estimated that the time required to crush sufficient annual aggregate would be the equivalent of a two month period throughout the year. The use of plant and associated activities would be restricted to between the hours of 7.00am and 7.00pm daily from Monday to Saturday inclusive.

Information on local aggregate suggests that the aggregate to be excavated would be dirty (ie a Sand Equivalent value smaller than 40) and that washing has little or no beneficial effect. Therefore washing is not likely to be used in the production of crushed roading aggregate.

The products that would be produced would be crushed roading aggregate to NRB specifications. It is also hoped that some of the scalplings will be further processed to produce various aggregate products, which would offset production costs.

The roading aggregate would be used by the Queenstown-Lakes District Council and others for roading construction and maintenance in the Wakatipu area.



## APPENDIX SIX

COUNCIL DECISION FOR CONSENT TO OPERATE AN AGGREGATE  
QUARRY LOCATED AT THE PROPOSED QUEENSTOWN-LAKES  
DISTRICT COUNCIL QUARRY SITE


The Council were of the opinion that the proposal was suitable for the site, in that the rural landscape values are able to be protected. It was also of the opinion that the location of the quarry would have a minimal effect on the amenities of the neighbourhood, and that it will be of economic benefit to the people of the district.

Therefore, the application was consented to subject to the following conditions:-

1. That upon the completion of the one year cycle of excavation the Queenstown-Lakes District Council shall restore the excavated area to a near natural state by leveling or land filling and shall regrass the area that has been excavated. A detailed plan of this operation shall be submitted to the Council's Engineer and the District Planner for their approval.
2. That in the extraction of any metal from the site the Queenstown-Lakes District Council shall be responsible for ensuring that any creeks are kept clear of any detritus arising from the quarry operations. It is also incumbent upon the Council to ensure that the floor of the excavation is constructed in a manner which will facilitate natural drainage.
3. That the margins of streams are to be left undisturbed for a distance of 15 metres on either side, with the exception of the accessway.
4. That the proposed location of the accessway and any crossings over shall be through the centre of the site.
5. That the applicant shall be responsible for the formation of a lay by on the eastern side of State Highway No. 6 at the entrance of the property to provide adequate waiting space for truck and trailer units who may wish to enter the site.
6. That the applicant shall be responsible for the sealing of the access from the edge of the seal of State Highway No. 6 to the road reserve boundary.
7. That the applicant shall comply with the Performance Standards in Ordinance 6.07 of the Rural A Zone.
8. That all areas of the site which are prone to the generation of dust shall be treated with either water or oil to keep dust to the minimum.
9. That the operation of machinery shall be carried out within the quarry and below the level of the natural ground surface contour.
10. That no machinery shall be operated within 100 metres from any of the boundaries of the site.

Should you not be satisfied with the decision of Council an appeal may be lodged with the Planning Tribunal, Wellington, not later than one month from the date hereof.

Yours faithfully,

  
W.J. Byers,  
District Manager.

GRL:cgw



## APPENDIX SEVEN

CRUSHING AND QUARRYING CONTRACT FOR THE  
QUEENSTOWN-LAKES DISTRICT COUNCIL AGGREGATE QUARRY

QUEENSTOWN-LAKES DISTRICT COUNCIL

SPECIFICATION FOR

QUARRYING AND CRUSHING  
REMARKABLES STATION QUARRY  
1987

Prepared by:

Duffill Watts & King Limited  
Consulting Engineers  
49 Shotover Street  
QUEENSTOWN

File No: 4041/22/1  
Job No: 13313  
Date: October 1987

SPECIFICATION FOR

PRINCIPAL

Queenstown-Lakes District Council

CONTRACT NAME

Quarrying and Crushing 1987  
Remarkables Station Quarry.

APPENDIX 1

CONTRACT NO:

13313

TENDERS CLOSE:

At 4pm on Tuesday  
1987 with the  
District Manager, Queenstown-  
Lakes District Council,  
Private Bag, Queenstown.

ENDORSEMENTS:

Tenders are to be sealed and  
endorsed - "Tender for  
Remarkables Station Quarry".

DEPOSIT WITH TENDER:

Nil

DAMAGES FOR NON-COMPLETION:

Nil

TIME FOR COMPLETION:

Contractor to state with  
tender.

MAINTENANCE PERIOD:

One month.

VALIDITY TIME:

The tender shall remain open  
for acceptance for 60 days  
from the tender closing date.

BOND:

A bond is required.

MARKET FLUCTUATIONS:

These shall not apply. Cost  
increases are to be allowed  
for and included in the  
tender price.

SPECIFICATIONS SECTIONS:

See Table of Contents.

## TABLE OF CONTENTS

<u>CLAUSES</u>		<u>PAGES</u>
1. General	1.1 - 1.22	1/1 - 1/6
2. Specific Contract Requirements	2.1 - 2.23	2/1 - 2/6

Form of Tender  
Schedule of Quantities  
Appendix I Work Statement  
Appendix II Grading samples

The following NRB Specifications are not bound in with this copy of the Specification but may be inspected at any office of Duffill Watts & King Limited. Although not bound in with this copy of the Specification these NRB specifications shall be read with and form part of the Contract Documents.

NRB B/2 1986 Basecourse Construction  
NRB M/4 1985 Crushed Basecourse

## SECTION 2

### SPECIFIC CONTRACT REQUIREMENTS

#### 2.1 LOCATION

The entry to the Remarkables Station Quarry is located on the east side of SH6 approximately 5.7km south of Frankton. The quarry access road is approximately 700m long running east from SH6 as shown on 13313/1,2 and 3.

#### 2.2 EXTENT OF WORK

The contract comprises:-

- (a) construction of subbase and basecourse on the access road
- (b) formation of a 3m wide access track from the access road to the centre of the west boundary, including subbase construction.
- (c) supply and installation of culverts
- (d) formation of an access track to the quarry operations area.
- (e) the control of dust from the quarry and access roads and tracks during contract.
- (f) the stripping and stockpiling of topsoil and overburden and the disposal of scrub and vegetation.
- (g) the quarrying screening, crushing and stockpiling of gravels.
- (h) the testing of the stockpiled gravels.
- (i) all associated work indicated, described or implied in the drawings, the specifications and the General Conditions of Contract.

#### 2.3 WORK BY OTHERS

The following work will be carried out by others under a separate contract prior to any work under this contract:-

- (a) Fencing, gates and cattlestop on the access road from SH6.
- (b) Access road formation to 6m width from SH6.
- (c) Layby and entry culvert construction at SH6 intersection. This is shown in Appendix I - the Work Statement for the Management Plan.

#### 2.4 SEQUENCE AND TIMING OF WORK

Within two weeks of acceptance of tender the Contractor shall submit to the Engineer a fully detailed programme for completing the Contract.

The Engineer may reject any programme which is in his opinion unsatisfactory. The Contractor shall not be entitled to any payment for costs arising from the Engineers rejection of a programme.

## 2.5 SANITARY CONVENIENCES

The Contract shall provide sanitary conveniences for the workmen employed on the Contract and these shall be maintained in a clean state to the satisfaction of the Local Inspector of Health.

## 2.6 POWER AND WATER FOR CONSTRUCTION

The Contractor shall be exclusively responsible for obtaining the power and water for all construction work included in this Contract. Arrangements for power must be made through the Local Power Authority, and all electrical work must be approved by that Authority. The Contractor shall be aware that there is no Council Water Supply available.

## 2.7 MATERIALS, PLANT AND LABOUR

The Contractor shall supply all materials, plant and labour necessary for the satisfactory completion of the work under the terms of the Contract.

All plant and equipment shall be fully operational on site for any of the work in hand before quarrying proceeds.

## 2.8 CONTRACTOR'S RESOURCES

The Contractor shall submit with his tender a list of the plant and machinery he will have available for use on this Contract and also state the size and organisation of the work force he proposes to use. He shall also provide a list of his subcontractors and material suppliers.

## 2.9 REPAIRING DAMAGE

It shall be the Contractor's responsibility to repair and make good to the satisfaction of the Engineer any damage that may be caused to existing streets, reserves, private land, buildings, fences, boundary pegs, services, (power, drainage, telephone) within the duration of the Contract and he shall indemnify the Queenstown-Lakes District Council against any claims made by persons in respect of damage caused by his operations.

## 2.10 COMPLETION DATE AND LIQUIDATED DAMAGES

The completion date is to be stated with the tender and preference will be given to tenderers able to complete production at the earliest date.

#### 2.11 DUST CONTROL AND AVOIDANCE OF NUISANCE

The whole of the works under this contract shall be carried out in such a manner as to cause no avoidable nuisance or inconvenience to the public.

The Contractor shall control the emission of dust from the access road, access tracks and quarry site from any cause. This shall be achieved by frequent watering or by oiling the exposed surfaces. If at any time the Engineer considers that the dust emission is excessive he may require the Contractor to carry out further work to control dust.

#### 2.12 HOURS OF WORK

The Contractor must at all times confine his work activities to the following times:-

7.00am to 7.00pm Monday to Saturday inclusive.

#### 2.13 PERFORMANCE STANDARDS:

The Contractor shall comply with the performance standards of Ordinance 6.07 of the District Scheme.

This requires that the noise level measured at the boundary of the site shall not exceed 60dBA, subject to correction.

The other requirements of Ordinance 6.07 with respect to atmospheric emissions, glare, vibration and electrical interference shall also apply.

#### 2.14 QUARRY OPERATION AREA

This will be at the southern central area of site in a location which will be marked on site by the Engineer. The following restrictions shall apply to the location of the quarry operation area:-

- (a) No machinery shall be operated within 100m from any of the boundaries of the site.
- (b) At no time shall more than 2ha of the land be used for the purpose of quarrying.
- (c) That the margins of streams are to be left undisturbed for a distance of 15m on either side.
- (d) That all areas of the site which are prone to the generation of dust shall be treated with either water or oil to keep dust to the minimum.
- (e) That the operation of machinery shall be carried out within the quarry and below the level of the natural ground surface contour.

#### 2.15 ACCESS ROAD AND TRACKS

The Contractor shall supply and construct the following road pavements to NRB Specification B/2, using aggregate from the quarry:-

- (a) Access Road - SH6 to quarry site entry
  - Subbase 180mm compacted depth AP80
  - Basecourse 80mm compacted depth AP40 to NRB Specification M/4
  - Top width of basecourse 4.5m
  - Crossfall 3% from centre, 3:1 shoulders.
- (b) Access Track - quarry site entry to centre of western boundary
  - Subbase 100mm compacted depth AP60
  - Top width of subbase 3m
  - Crossfall 3% from centre, 3:1 shoulders.
- (c) Access Track - centre of western boundary to quarry operations area
  - Width and standard to suit Contractor's operations.

Prior to constructing the access track pavement the Contractor shall strip and form the tracks to the required width, with a maximum gradient of 1 in 8.

#### 2.16 CULVERTS

The Contractor shall supply and construct 375mm diameter flush jointed reinforced concrete Class S culverts 7.3m long at each stream crossing, complete with stacked stone headwalls. The minimum cover over the culvert shall be 500mm.

#### 2.17 FENCING

The quarry site already has a stock fence around the perimeter and the Contractor is required to maintain this fence as it is at present and allow for this item under Establishment.

#### 2.18 STRIPPING

The Contractor shall remove and dispose of all scrub and vegetation, strip the topsoil and overburden to separate stockpiles from the quarry operations area. The overburden stockpile shall be placed in a local hollow or depression and shaped to suit the surrounding landform.

#### 2.19 QUARRY OPERATIONS

The Contractor shall form a relatively level, free draining work area with sufficient room for stockpiling the specified quantity of aggregate. The work area shall be a maximum of 2ha at any one time and be maintained in a clean and tidy state with all rubbish and waste buried or removed from the site. The surface shall be graded if necessary to eliminate puddles and wet areas.

The excavated area shall be left with batters not steeper than 1H:2V. The Contractor shall outline to the Engineer his proposed method of quarrying prior to work commencing, and shall modify the method if required by the Engineer.



## 2.20 AGGREGATE SIZE AND SPECIFICATION

The Contractor shall supply in stockpile the following aggregate for road pavement construction:-

- (a) AP 80 SUBBASE - This shall be evenly graded from 80mm maximum size down to fines and does not necessarily have to be crushed.
- (b) AP 60 SUBBASE - This shall be evenly graded from 60mm maximum size down to fines and does not necessarily have to be crushed.
- (c) NRB M/4 AP 40 BASECOURSE - This shall be crushed and screened and shall be evenly graded within the following grading envelope:

<u>SIEVE SIZE</u>		<u>PERCENTAGE PASSING</u>
37.5	mm	100
19.0	mm	66 - 81
9.5	mm	43 - 57
4.75	mm	28 - 43
2.36	mm	19 - 33
1.18	mm	12 - 25
600	um	7 - 19
300	um	3 - 14
150	um	10 max.
75	um	7 max.

It is expected that scalping will be necessary to achieve these grading limits.

In each of the three aggregate fractions between 37.5mm and 4.75mm not less than 70% by weight shall have two or more broken faces.

The stockpiles of these four materials must be kept clear from each other with no overlapping and with clear access to each stockpile. The Contractor is not to remove any material from stockpile other than for the accessway and tracks.

## 2.21 MATERIAL TESTING

The Contractor shall arrange two representative samples of each of the three aggregate types for testing as followings: NRB M/4 AP 40 Basecourse will require: Grading (NZS 4402 Part 1:1980 Test 9(A) or 9(B), Proportion of Broken Rock, Crushing Resistance (NZS 3111:1980 Sec 15), Sand Equivalent (NZS 4402 Part 1:1980 Test 7) Weathering Resistance (NZS 3111:1980) tests. AP 80 and 60 subbase - Grading only. The cost under this item shall be included under the Schedule item Establishment.

The Contractor shall be held responsible for satisfactory results from the Grading and Proportion of Broken Rock tests only. No payment will be made until satisfactory results are achieved. In this respect it is recommended that the Contractor carry out field tests to ensure the correct grading requirements are being achieved.

Appendix II is provided for information only and is not to be construed as a guarantee as to grading. The two gradings (conducted in accordance with NZS 4402 Part 1:1980 Test 9(A)) are of samples collected from a crushing trial performed on aggregate from the Remarkables Station Quarry site. Approximately 40 m<sup>3</sup> of aggregate was collected from test pit 13 (see map 2), the aggregate was processed by two methods :  
(i) oversize and -25mm scalped out and the remaining crushed (13SC)  
(ii) oversize screened out and remainder crushed (17C)  
These limited test results suggest that to obtain an M4 grading scalping will be required.

## 2.22 BASIS OF PAYMENT

All scheduled items shall be paid for the net in-place quantities, measured on-site and agreed by the Contractor and the Engineer.

The stockpiled aggregates shall be maintained in a trim and tidy state and stacked high to save space. Prior to completion of the work the Contractor shall neatly level off the tops of the stockpiles to assist in accurate measurement.

The Contractor shall supply to the Engineer records of quantities delivered to the stockpile or put through the screen or crusher. On confirmation by the Engineer progress payments will be made on the loose measure stated in the Contractors claims, multiplied by 0.90 to convert to approximate stockpile measure.

## 2.23 CLEANING UP AND REMOVAL OF SURPLUS MATERIALS

On completion of the Contract, the Contractor shall ensure that all reinstatement is complete and shall then remove all surplus material, sheds and rubbish from the area and leave the site of work in a clean and tidy state. Should the Contractor fail to carry out this cleaning up then the Engineer will hire another Contractor to clean up the site and the cost of this work will be deducted from the final Contract Payment.

The Contractor shall inspect the streams adjacent to his work area and remove any rubbish or detritus arising from his operations.

## APPENDIX EIGHT

ENVIRONMENTAL ASSESSMENT QUESTIONNAIRE FOR THE TWELVE  
MILE +45M DELTA SOURCE AREA PROSPECTING LICENCE APPLICATION

MD 2

# **APPLICATION FOR PROSPECTING LICENCE UNDER THE MINING ACT 1971 FOR AN AREA OVER 40 HECTARES**

Secretary of Energy,  
P.O. Box 6342,  
Te Aro,  
WELLINGTON.

NOTE: Original plus 8 copies required.

No.: .....

Date and Time Received

Name of Applicant<sup>1</sup>: Lake County Council

Address: Local Government Office, Stanley Street, Queenstown Telephone No.: 27330  
(Full Street Address)

Occupation: Local Body

Registered office: Local Government Office, Stanley Street, Queenstown

Address for service: c/- Macalister Todd Phillips, Solicitors, 54 Shotover Street, Queenstown

Land description<sup>2</sup> (continue on separate sheet if necessary): Recreation Reserve 81.7 ha (approximately)  
being part Section 39, Block IV, Mid-Wakatipu District. Commencing at an old peg of  
Survey Office Plan No.19497 situated 607.70 metres due east of trig E, Mid-Wakatipu  
S.D. and proceeding thence in a generally north easterly direction along (Cont..see  
attached sheet)

Methods of prospecting and work programme<sup>3</sup> (continue on separate sheet if necessary): Sampling by excavation  
of approximately ten test pits taking approximately three days to dig,  
Processing would take another two weeks which would involve crushing of aggregate (Cont..see  
attached sheet)

Number of years for which licence is required: three years (maximum 3 years).

Names of owners and occupiers, etc.<sup>4</sup>: Commissioner of Crown Lands - Department of Lands & Survey,  
P.O. Box 896, Dunedin

Notice posted on ground (date)<sup>5</sup>: 3rd September 1986

Environmental Assessment (attached)<sup>6</sup>: Yes

**<sup>7</sup> APPLICATION FEE \$50 PLUS FIRST YEAR'S RENT  
MUST ACCOMPANY THIS APPLICATION**

I the undersigned being the applicant for the licence or his duly authorised agent do hereby certify that the above particulars are correct.

Dated at Queenstown this 3rd day of September 1986

Lake County Council by its Solicitors and  
duly authorised agents Macalister Todd  
Phillips, per: *[Signature]*

Signature of Applicant

1-7 For notes on preparation of Application,  
see overleaf.

**Schedule as to Land**

the northern boundary of Section 39 on a bearing of 54 degrees 17 minutes 30 seconds for a distance of 883.2 metres; thence in a generally east-north-east direction on a bearing of 75 degrees 18 minutes 30 seconds for a distance of 785 metres to meet the northern cadastral boundary of Lake Wakatipu; thence proceeding in a generally southerly and then generally westerly direction along the said cadastral boundary of Lake Wakatipu for a distance of approximately 2075 metres; thence proceeding due north on a bearing of 360 degrees 00' 00" for a distance of approximately 316 metres to return to the point of commencement as more particularly shown on the attached plan.

#### **Schedule as to Work Programme**

obtained to establish crushing resistance. Areas of appropriate aggregate having been obtained, a testing programme of source areas would be undertaken to establish which source area was the most efficient and effective aggregate to process and use for roading aggregate.

Prospecting Licence Number.....  
(for Mines Division use only)

Applicant's Name ...LAKE COUNTY COUNCIL.....

## EXISTING ENVIRONMENT

### SECTION ONE

#### 1.0 LOCATION

1.0.1 County .....Lake County.....

1.0.2 Nearest town .....Queenstown.....

1.0.3 Cadastral NZMS 261 map number .....NZMS 1 Wakatipu S 132.....

1.0.4 Survey district(s) and block number(s).....

.....

1.0.5 Describe the general location of the area

Twelve Mile Creek delta and terraces

1.0.6 Provide a topographical location map showing approximate application boundaries at a scale of 1:63,360 or 1:50,000. If possible plot any special features identified in this Environmental Assessment Questionnaire. As shaded orange on S. 132 attached hereto

#### 1.1 TOPOGRAPHY

Tick the appropriate boxes and provide appropriate percentages of these. eg 50% river bed 30% river terraces 20% mountainous

- ☒ river bed 10%
- ☒ river terraces 90%
- ☐ dunes
- ☐ estuarine
- ☐ beach

- ☐ rolling
- ☐ hilly
- ☐ mountainous
- ☐ swamp
- ☐ other (give details)

## 1.2 VEGETATION

### 1.2.1 Tick the appropriate boxes.

- |  |   |
|--|---|
| <input type="checkbox"/> pasture                           | <input checked="" type="checkbox"/> native forest |
| <input type="checkbox"/> scrub eg gorse                    | <input type="checkbox"/> tussock                  |
| <input type="checkbox"/> land cleared for planting         | <input type="checkbox"/> swamp                    |
| <input checked="" type="checkbox"/> exotic forest eg pines | <input type="checkbox"/> orchard/market garden    |
| <input type="checkbox"/> sand dune                         | <input type="checkbox"/> alpine                   |
| <input checked="" type="checkbox"/> regenerating           | <input type="checkbox"/> tidal flats              |
| <input type="checkbox"/> other (give details)              | <input type="checkbox"/> virgin forest            |
|  | <input type="checkbox"/> cut over forest          |
|  | <input type="checkbox"/> pakahi                   |

### 1.2.2 Describe the types of vegetation and approximate percent of coverage. eg 50% pine forest 20% pasture 30% gorse

80% regenerating; Bracken, Manuka, general scrub  
10% Native Beach Forest  
10% Bluegums & Pines

## 1.3 PRESENT LAND USE

### 1.3.1 What is the land being used for? eg farming (type), orchards, market garden, residential, industrial, reserve (type), national park, marine park, state forest, forest park, ecological area, sanctuary, recreational etc.

Recreation Reserve

### 1.3.2 Give the approximate percent of the different types of land use.

100% Reserve



#### 1.4 BIRDLIFE, WILDLIFE, FRESHWATER AND MARINE LIFE

What types of birdlife, wildlife, freshwater and marine life are present in the area (NB None is rarely an acceptable answer)

- Birdlife:  
Sparrow, blackbird, thrush, bellbird, waxeye, wood pigeon, fantail, gray warbler, teal, mallard, seagull.
- Wildlife:  
Rabbit and hare
- Freshwater life:  
Brook trout and brown trout

#### 1.5 WILDLIFE HABITATS

Are there any special ecological features, wildlife features or habitats. eg caves, bird nesting sites, beaches, seal colonies, river bed etc.

The proposed area has the Twelve Mile Creek running approximately through the central zone and the south and east boundary of the proposed area is Lake Wakatipu. Therefore, riverbed and lake beach habitats are present within the proposed area. However, there is no special ecological feature such as a major nesting site or unique breeding sites within the proposed area.

#### 1.6 HISTORICAL AND ARCHAEOLOGICAL SITES

Are there any historical or archaeological sites within the area? Give details. These include sites of early Maori occupation, early European habitation, old farming and old mining operations.

Your attention is drawn to the Historic Places Act 1980 which makes provision for the protection of archaeological sites. (Contact local historic places file keeper).

No 3. however some minor gold mining tailings are present at certain places. In Wakatipu area has only minor attraction as to gold mining.

#### 1.7 PRESENT PUBLIC USE

Is there public use of the application area and immediate vicinity. If so, detail the location.

Yes, general river bed area and lake frontage

##### 1.7.1 What are these public uses eg fishing, boating, walking, picnics etc.

Fishing, boating and picnics - i.e. recreational

##### 1.7.2 How often is the area used by the public?

Rarely. Reasonably isolated from normal tourist areas.

#### 1.8 PLANNED ALTERNATIVE LAND USES

What are the proposed future uses for the area? (This information can be obtained from the landowner or the administrative authority).

General Recreational purposes.

#### 1.9 PREVIOUS MINING

##### 1.9.1 Has the area been mined or prospected before?

Yes, minor gold mining tailings are present but not on any intensive basis.

##### 1.9.2 Are there any underground workings?

Do you intend to enter these?

No

#### 1.10 OTHER POINTS

Is there anything else that has not been covered fully in section one? No  
eg local fire hazard, erosion, areas of scientific interest, existing environmental problems and damage. Give details and show on location map. N/A

### SECTION TWO

#### 2.0 ACCESS

2.0.1 Describe your proposed access to the land for both people and equipment  
eg helicopter, vehicle (give type), walking track, formed roads, unformed legal roads.

Metal surfaced road to beach on Lake Wakatipu

2.0.2 Will any road construction or upgrading of existing roads, tracks, or formation of helicopter pads be required? Yes

If so

a What works are necessary?

Upgrading of existing road so as to provide reliable access.

b What type of machinery will be used for these works?

Loader and truck

**2.0.3 How frequently will the access routes be used?**

Daily to weekly as may be required by demand.

**2.0.4 Approximately how many and what type of vehicles will be used?**

1 Loader  
2 Trucks

**2.0.5 Will there be any other users of this area?**

Not for any mining purpose

**2.1 BUILDINGS/CAMPS**

Do you intend to erect any buildings/camps in the area? No

If so,

a What size and type eg tents, relocatable huts etc. N/A

b How many? N/A

c What is the purpose of each building? N/A

d Will they be able to be easily removed? N/A

e How will they be removed? N/A

## 2.2 SAMPLING

2.2.1 Describe the methods of sampling to be used. If earthmoving machinery is to be used, describe the sampling method and type of machinery.

Grab samples from outcrops and channel samples from backactor holes so as to assess quality of aggregate and gravels

2.2.2 Give approximate size of samples to be taken.

30 kilograms

2.2.3 Will the removal of waste rock be required to take samples?

No

2.2.4 Is bulk sampling contemplated? If so, what size will the samples be and how many bulk samples will be taken? (Please note maximum size usually allowed is 20 cu metres, including overburden and no more than one bulk sample per hectare unless authorised by the Inspector of Mines).

No

## 2.3 GEOPHYSICAL SURVEYS

If you plan to carry out geophysical surveys No

2.3.1 What type of geophysical survey? N/A

2.3.2 Will any gridding be necessary? N/A

2.3.3 Will explosives be used for this survey? No

2.3.4 What will their effect be on the wildlife and environment? N/A

## 2.4 EXPLOSIVES

Do you intend to use explosives? .....<sup>No</sup>  
If so, describe:

2.4.1 Type and quantity per blast N/A

2.4.2 Purpose N/A

2.4.3 Who will be using these explosives? N/A

2.4.4 What qualifications does he have to carry out this work? N/A

## 2.5 EARTHMOVING MACHINERY

Do you intend to use earthmoving machinery .....<sup>Yes</sup>  
If so, describe:

2.5.1 Type and size

Volvo 140hp wheeled Loader or a similar wheeled Loader

2.5.2 Purpose

To remove aggregate from site

2.5.3 Will machinery be used in watercourses? Yes

2.6 WATER

NOTE: The applicant should discuss his water requirements with the regional water board.

Will you require water for prospecting? .....<sup>No</sup>.....

If so

2.6.1 What quantity?

N/A

2.6.2 From what source(s) do you propose to take this water? N/A

2.6.3 How do you propose to take this water? N/A

2.6.4 Do you propose to recycle the water? N/A

2.6.5 Where will the water be discharged? Give details N/A

2.6.6 Give details of any settling ponds. N/A

**2.7 EFFECTS ON WATERBODIES eg rivers, lakes, groundwater, sea**

**2.7.1** Will your operations be carried out on any of the above waterbodies?  
If so, give details

Yes, The Twelve Mile Creek

**2.7.2** What operations (if any) will be carried out in the bed of streams or rivers?

- (i) the removal of aggregate
- (ii) crossing of the creek by machinery

**2.7.3** What operations (if any) will be carried out in the watercourse of streams or rivers?

Same as above

**2.7.4** What is the capacity of any machinery to be used?

2-3m<sup>3</sup>

**2.7.5** In the case of a suction dredge state the total horse power.

N/A

**2.8 STREAM SEDIMENT LOAD**

Will your activities cause an increase in stream or river sediment load? If so give details and your plans to minimise this?

Yes, Machinery activity within the watercourse will be kept to the minimum so as to ensure the quality of the water in the Twelve Mile Creek is not affected.



## 2.9 IMPACT ON VEGETATION

What is required in the way of vegetation clearing?

The overburden (0.5m) and vegetation cover will have to be removed from the immediate vicinity being used for the extraction of the gravel and aggregate.

## 2.10 POSSIBLE TYPE OF MINING

Briefly describe the likely type of prospecting.

may develop from this

An open pit face from which aggregate can be removed and transported out of area for use in roading and associated activities.

### 3.0 OVERALL IMPACTS

The prospecting activities may affect the following: vegetation, waterways, birdlife, wildlife, existing land use, ecology, historical and archaeological sites, present public use and planned future use. Please comment on the likely effect of each stage of the prospecting programme on each of the above. (Include visual impacts, noise and dust)

The prospecting programme will involve:

- (i) The collection of 30kg grab samples from outcrops in the area. These samples will be collected by hand.
- (ii) The use of a backactor to excavate approximately ten test pits which will take approximately three days to dig. Test pits are usually 1m wide by 4m long by 4m deep. Once the test pit is excavated, several 30kg channel samples will be collected. The material removed during excavation will then be replaced and the surrounding area is cleaned up leaving the area as unmarked as possible.
- (iii) Grab and channel samples collected will then be tested by National Roads Board specifications for grading, crushing resistance and sand equivalent.

The collection of the 30kg grab samples will have little or no effect on vegetation, waterways, birdlife, wildlife and ecology of the area due to the size of the sample and method of removal.

The vegetation surrounding the test pits will be disturbed during excavation. However, regeneration of the vegetation is expected to occur rapidly. Therefore, each test pit will only affect a small area in the short term.

The waterways will not be affected as no test pits will be excavated in the creek bed.

There will be a minimal disturbance to the birdlife, wildlife and general ecology of the area during excavation of the test pits (three days) and the time required for regeneration of the vegetation, i.e. only short term.

The existing land use is a Recreational Reserve. The main attraction of the reserve is the creek bed and waterfront. The test pits will be restricted to areas other than the creek bed and waterfront; therefore, excavation of the test pits is expected to have minimal short term effect on existing land use, present public use and no effect on the planned future use.

Minor gold mining tailings are present in the area. However, these will not be affected, as the test pits will be restricted to other areas.

To be completed by the person answering the questionnaire.

Name:

Charle Robert Watts

Signature:

CR Watt

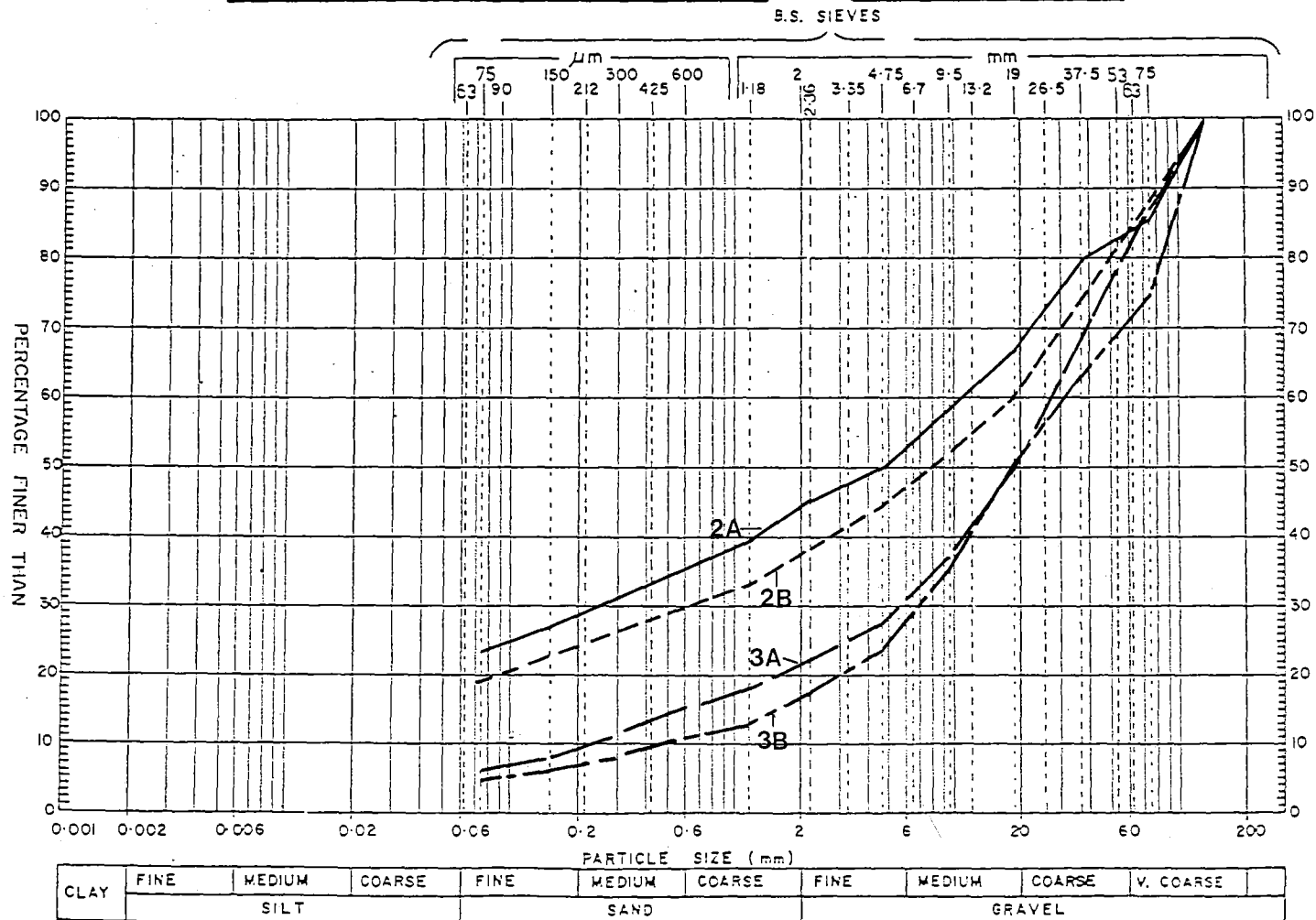
Designation:

B.Sc (Geology)

## APPENDIX NINE

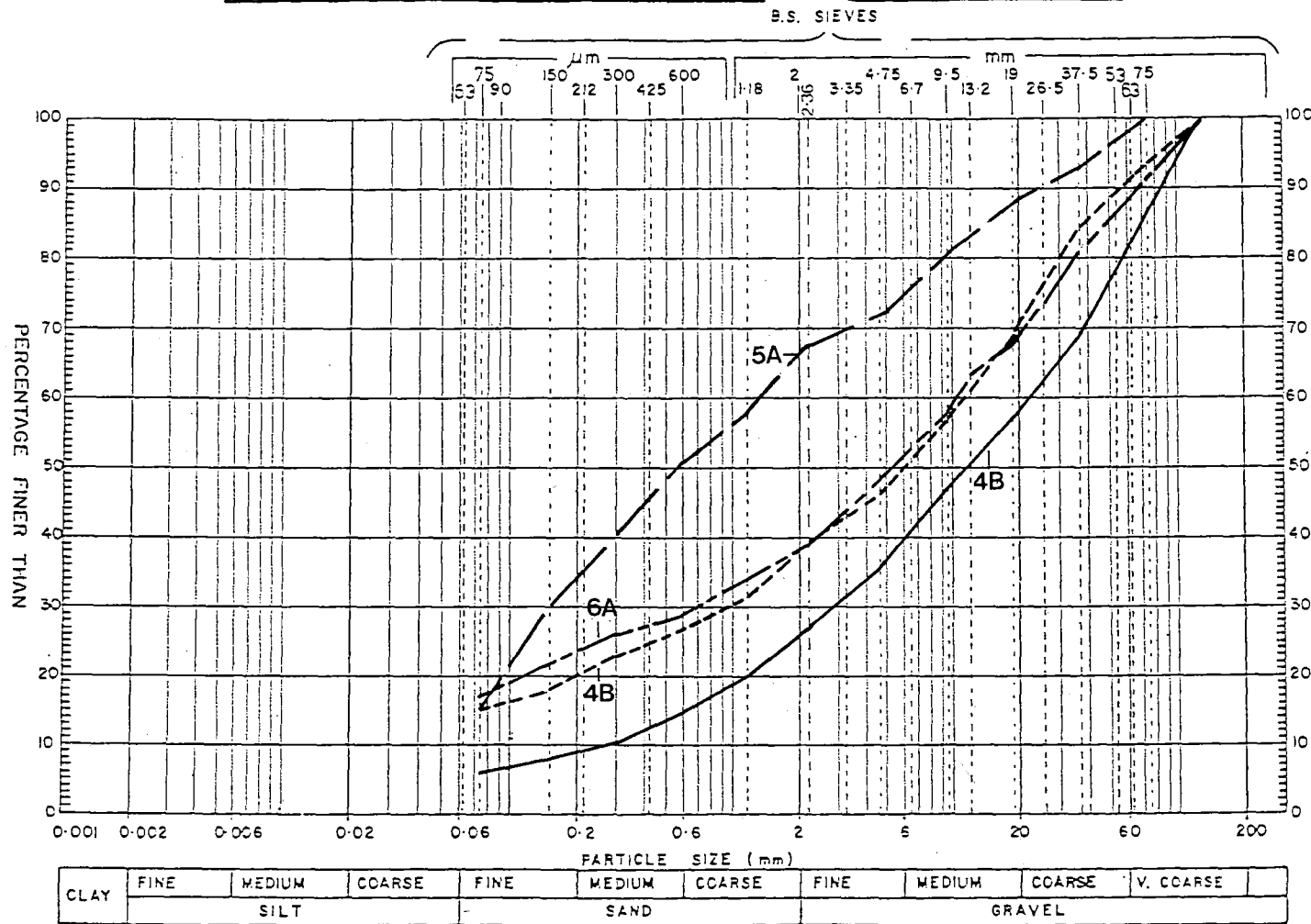
## PARTICLE GRAIN SIZE DISTRIBUTIONS

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT



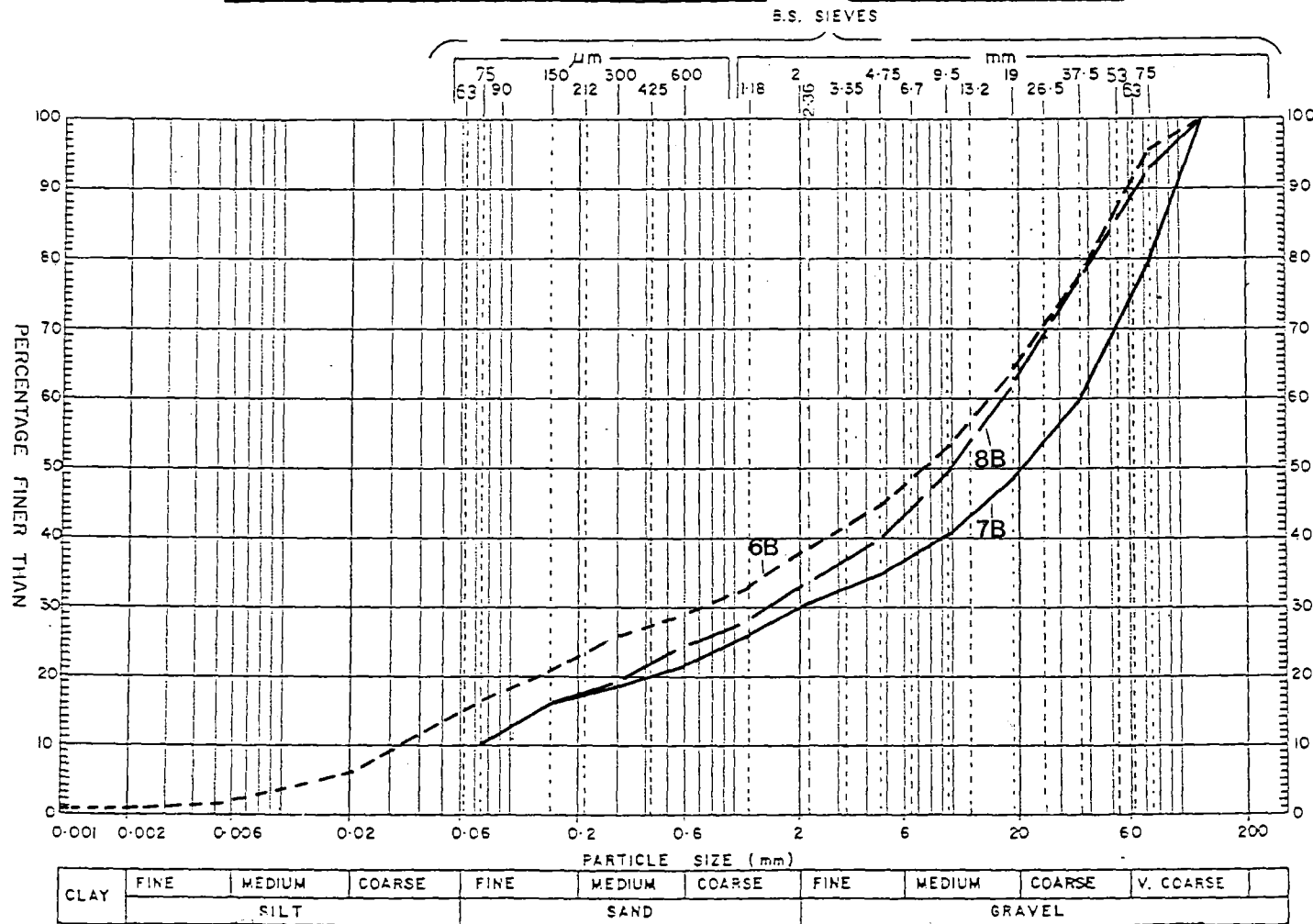
Particle size distribution of kame terrace samples 2A, 2B, 3A and 3B.

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT



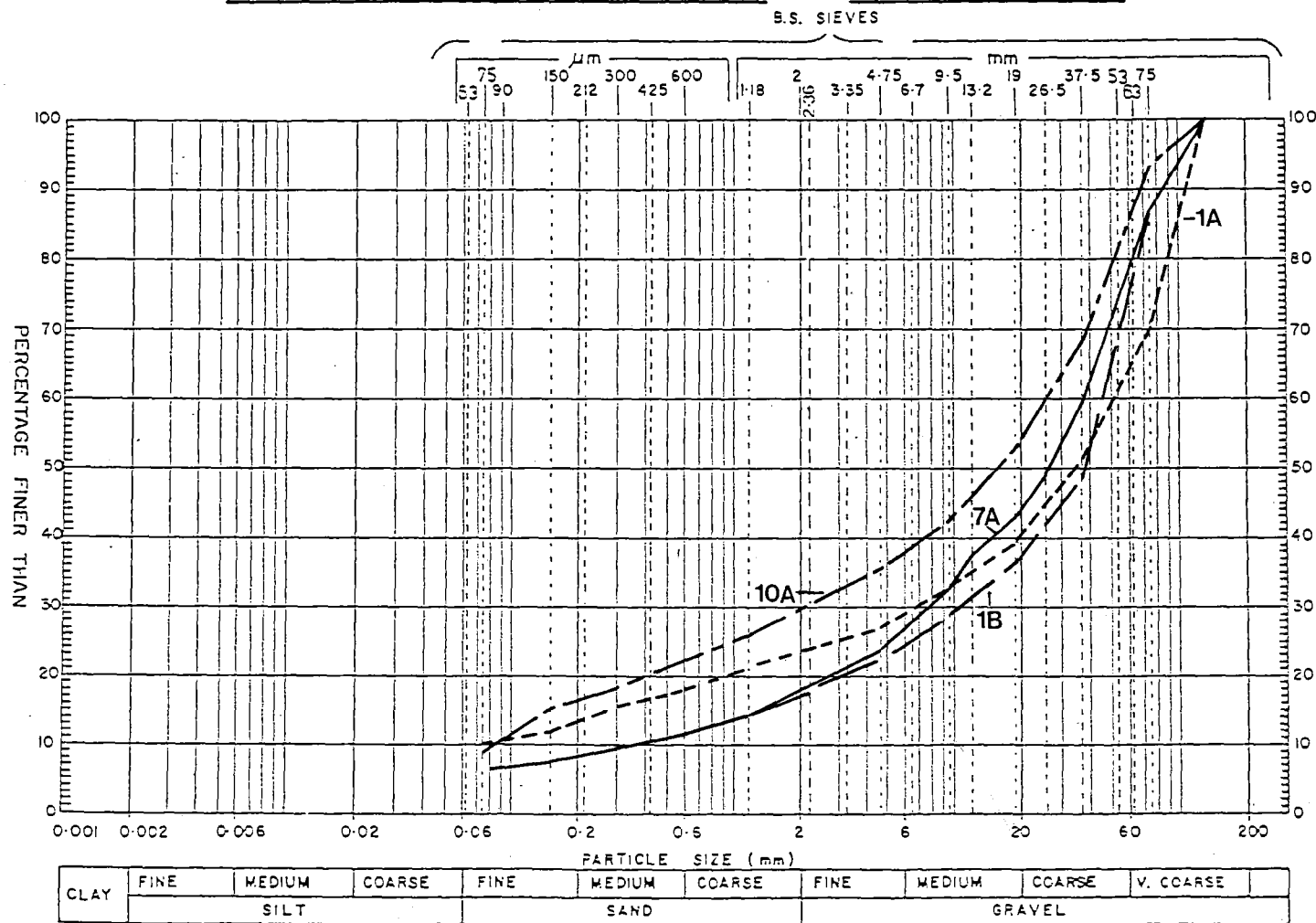
Particle size distribution of kame terrace samples 4A, 4B, 5A, and 6B.

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT



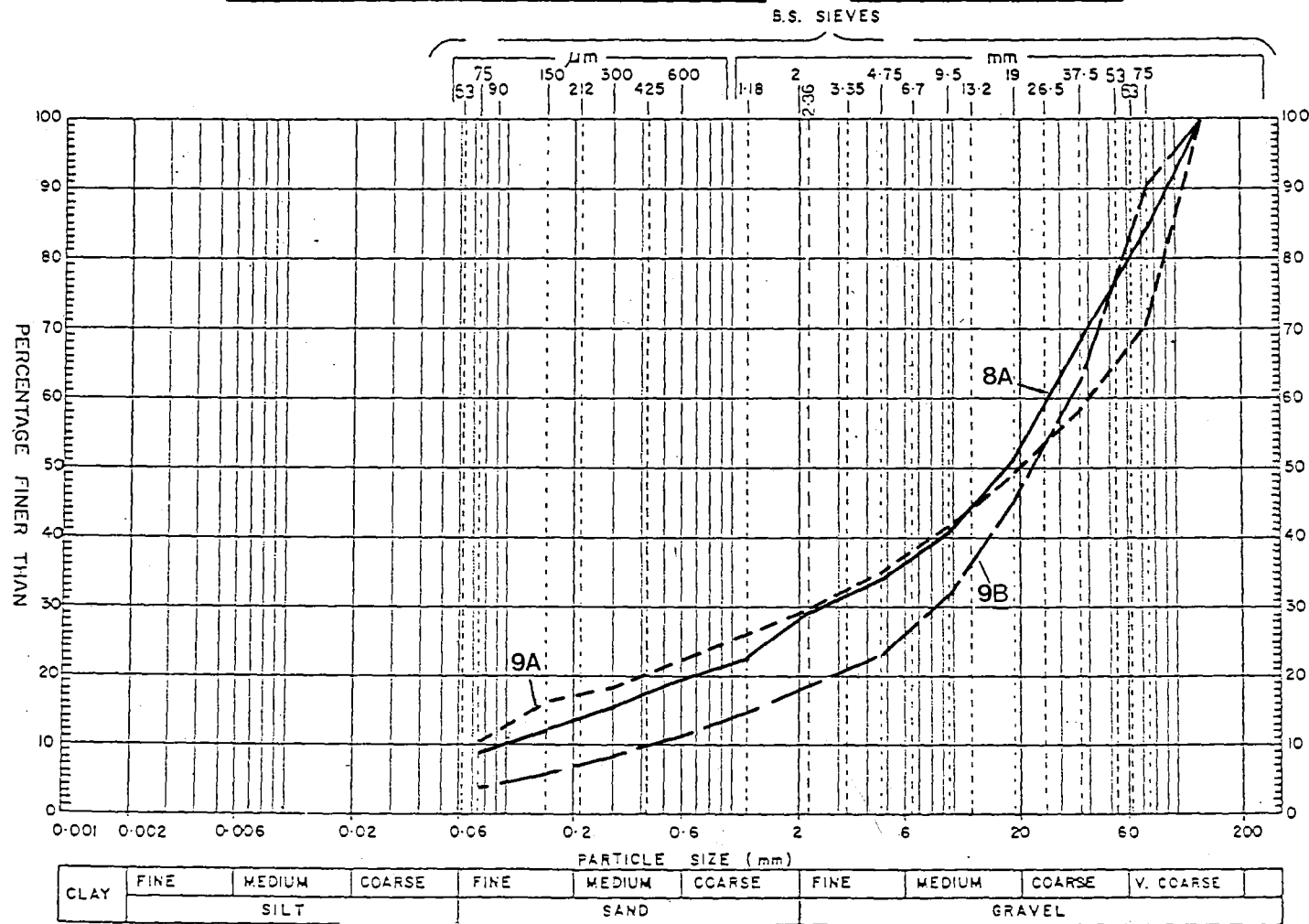
Particle size distribution of kame terrace samples 6B, 7B, and 8B.

# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT



Particle size distribution of fan alluvium samples 1A, 1B, 7A and 10A.

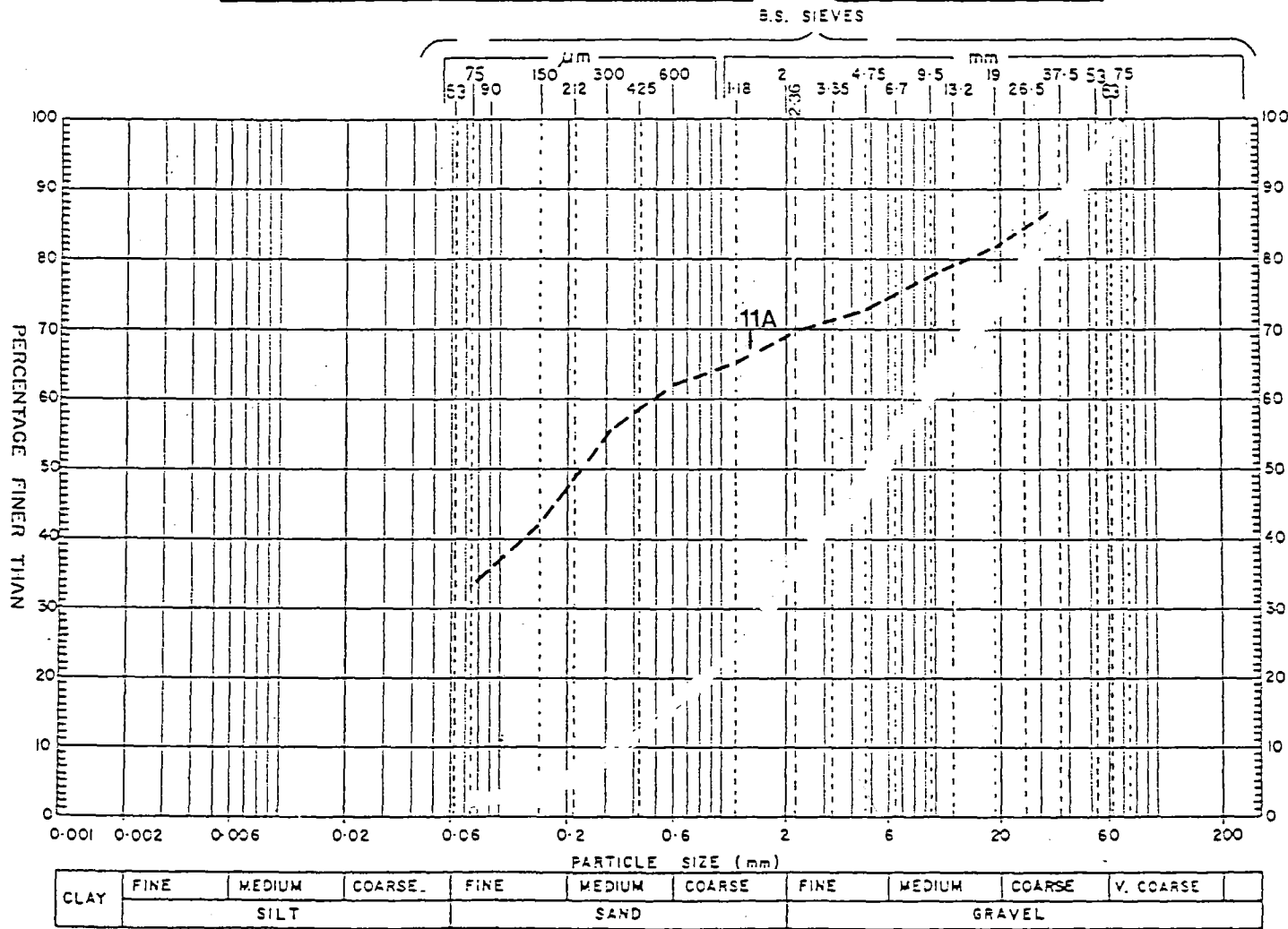
# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT



Particle size distribution of fan alluvium samples 8A, 9A, and 9B.



# PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT



Particle size distribution of till sample 11A.

APPENDIX TEN  
GEOTECHNICAL TESTING PROCEDURE

## A10 GEOTECHNICAL TESTING PROCEDURE

### A10.1 Sand Equivalent Procedure

A brief outline of the test procedure is as follows:

A sample passing the 4.75mm sieve is vigously shaken with a weak flocculating agent in a sand equivalent cylinder and allowed to settle for twenty minutes. The fines form a layer on top of the sand and the sand equivalent value is detirmined by calculating the ratio of the depth of the sand to that of the sand plus fines.

### A10.2 Weathering Resistance Procedure

A brief outline of the test procedure is as follows:

The aggregate is exposed to ten cycles of soaking and drying (at 110<sup>0</sup>C); after each cycle the material is rolled with a smooth steel roller 100 times. For each cycle the same water is used. After the tenth soaking and rolling, the sample and water are re-united, boiled, agitated and strained over a 4.75mm sieve. The Cleanness value was detirmined in accordance with NZS 3111 Test 13. The "dirty" water from the weathering resistance test is vigorously shaken in a sand equivalence cylinder with a weak flocculating agent and allowed to settle for twenty minutes. The amount of sediment is correlated with a table which provides the Cleanness value.

### A10.3 Crushing Resistance Procedure

A brief outline of the test procedure is as follows:

A sample passing a 13.2mm sieve and retained on a 9.5mm sieve is placed in a cylinder and plunger apparatus. Load is applied at a uniform rate to the plunger so as to cause a

penetration of approximately 20mm in ten minutes. The amount of crushed material passing a 2.36mm sieve is determined. The load required to produce 10% of material passing the 2.36mm sieve is said to be the crushing resistance value.

#### A10.4 Atterberg Limits Procedure

The liquid limit is determined by placing approximately 30g of sample in a liquid limit device cup, and a grooving tool is then used to divide the sample. By turning the handle of the machine the cup is lifted and dropped repeatedly until the sample flows into the bottom of the cup. The water content of the sample at 25 blows is defined as the liquid limit.

The plastic limit is determined by rolling a 10g sample between the hand and glass plate to a diameter of 3mm. When the soil ceases to be plastic at 3mm diameter and crumbles, the moisture content at this point is said to be the plastic limit.

The Plasticity Index is calculated by using the following formula:  $PI = LL - PL$ .

In some circumstances the liquid limit cannot be obtained, as the soil sample slides on the liquid limit device cup rather than flowing. When this occurs an alternative method of determining the liquid limit, the cone penetration limit, can be used. While the cone penetration limit of a soil is not a liquid limit, for cone penetration limit values below 50, the cone penetration limit and liquid limit may be assumed to be coincidental (Sherwood and Ryley 1970). The cone penetration limit was determined in accordance with NZS 4402 Part 1:1980 Test 5.

The cone penetration limit is determined by relating

the depth a weighted cone will penetrate a soil sample at different water contents. The cone penetration limit is defined as being the water content of the soil sample when the cone penetrates the sample 20mm.

#### A10.5 Clay Index Procedure.

The Clay Index test is completed on a 2g sample passing the 75mm sieve. The sample is titrated with Methylene Blue, which is absorbed by swelling clays. Therefore, when an excess of Methylene Blue is noted during the titration, the amount of dye titrated is used to calculate the Clay Index value.

#### A10.6 X-ray Diffraction Procedure.

Clay size material ( $<2\mu\text{m}$ ) was collected from hydrometer columns, once the particle size analysis was completed. Clay size material from the weathered fines was collected by preparing pipette samples of the weathered fines material and collecting the clay size samples at the appropriate times. Oriented clay mounts were prepared by transferring 2ml of clay suspension with an eye dropper to the X-ray Defraction slide. The slide was then partially dried with the use of a heat lamp, but not allowed to bake. This provides sufficient time to produce an oriented clay mount but insufficient time for segregation of different clay sizes and composition to occur.

#### A10.7 Los Angeles Abrasion Procedure.

A washed and dried 5000g sample conforming to grading A is placed in the abrasion machine. A standard 12 steel balls are added as a charge to the abrasion apparatus and rotated

500 times at 30-33rpm. The fines (<1.68mm) produced are expressed as a percentage of the original mass. The percentage obtained is then defined as being the Los Angeles abrasion value for that sample.

## APPENDIX ELEVEN

### LITHOLOGICAL ANALYSIS

Percent (by weight) of lithological type retained on 75mm sieve.										
Lithological Type.	Kame terrace									
	2A	2B	3A	3B	4A	4B	5A	6B	7B	8B
Quartz	0	0	0	0	0	0	0	0	0	0
Schist	100 (2)	100 (2)	100 (3)	0	0	37 (1)	0	100 (1)	45 (2)	100 (1)
Greywacke	0	0	0	100 (2)	100 (1)	63 (2)	0	0	55 (1)	0
Percent (by weight) of lithological type retained on 37.5mm sieve.										
Lithological Type.	Kame terrace									
	2A	2B	3A	3B	4A	4B	5A	6B	7B	8B
Quartz	0	0	15 (4)	0	29 (3)	11 (2)	20 (1)	5 (1)	0	0
Schist	100 (6)	100 (15)	62 (5)	25 (1)	61 (5)	46 (8)	80 (4)	68 (9)	66 (9)	75 (8)
Greywacke	0	0	22 (4)	75 (7)	10 (1)	43 (8)	0	27 (2)	34 (4)	25 (2)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Kame terrace lithological analysis of sample retained on 75mm and 37.5mm sieve.



Percent (by weight) of lithological type retained on 19.0mm sieve.										
Lithological Type.	Kame terrace									
	2A	2B	3A	3B	4A	4B	5A	6B	7B	8B
Quartz	11 (13)	11 (10)	13 (16)	17 (22)	15 (20)	24 (28)	13 (13)	29 (25)	8 (6)	13 (14)
Schist	80 (59)	69 (52)	58 (49)	51 (56)	63 (53)	51 (42)	64 (15)	62 (59)	85 (55)	63 (70)
Greywacke	9 (5)	19 (12)	30 (29)	32 (33)	22 (18)	25 (20)	24 (3)	10 (8)	6 (4)	24 (27)
Percent (by weight) of lithological type retained on 9.5mm sieve.										
Lithological Type.	Kame terrace									
	2A	2B	3A	3B	4A	4B	5A	6B	7B	8B
Quartz	31 (28)	26 (25)	13 (24)	22 (46)	34 (27)	42 (46)	10 (28)	20 (51)	15 (104)	9 (13)
Schist	67 (57)	60 (70)	64 (71)	52 (91)	31 (27)	35 (46)	70 (28)	70 (51)	81 (104)	70 (106)
Greywacke	2 (2)	14 (11)	23 (22)	25 (37)	30 (15)	24 (28)	20 (6)	10 (5)	4 (3)	22 (24)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Kame terrace lithological analysis of sample retained on 19.0mm and 9.5mm sieve.

Percent (by weight) of lithological type retained on 4.75mm sieve.										
Lithological Type.	Kame terrace									
	2A	2B	3A	3B	4A	4B	5A	6B	7B	8B
Quartz	34 (114)	22 (84)	21 (85)	34 (96)	40 (102)	35 (135)	15 (30)	30 (55)	15 (56)	15 (57)
Schist	63 (180)	72 (251)	59 (213)	49 (151)	44 (145)	47 (168)	75 (197)	58 (124)	79 (158)	71 (235)
Greywacke	3 (8)	6 (18)	19 (52)	16 (44)	16 (32)	18 (36)	10 (22)	12 (20)	6 (9)	14 (45)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Kame terrace lithological analysis of sample retained on 4.75mm sieve.

Percent (by weight) of lithological type retained on 75mm sieve.								
Lithological Type.	Fan alluvium						Till	Twelve Mile delta
	1A	1B	8A	9A	9B	10A	11A	12.1
Quartz	0	0	0	0	0	0	0	0
Schist	100 (2)	100 (4)	100 (2)	100 (2)	100 (2)	0	0	0
Greywacke	0	0	0	0	0	0	0	0

Percent (by weight) of lithological type retained on 37.5mm sieve.								
Lithological Type.	Fan alluvium						Till	Twelve Mile delta
	1A	1B	8A	9A	9B	10A	11A	12.1
Quartz	4 (18)	12 (2)	22 (2)	0	5 (2)	0	0	4 (1)
Schist	96 (43)	68 (12)	74 (9)	100 (8)	66 (5)	95 (19)	0	53 (8)
Greywacke	0	20 (2)	4 (1)	0	29 (16)	5 (1)	100 (5)	43 (2)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Fan alluvium, till and Twelve Mile delta lithological analysis of sample retained on 75mm and 37.5mm sieve.

Percent (by weight) of lithological type retained on 19.0mm sieve.								
Lithological Type.	Fan alluvium						Till	Twelve Mile delta
	1A	1B	8A	9A	9B	10A	11A	12.1
Quartz	31 (78)	15 (15)	8 (11)	6 (3)	12 (15)	4 (3)	23 (8)	22 (21)
Schist	63 (43)	77 (56)	81 (74)	70 (30)	71 (69)	88 (72)	29 (10)	74 (74)
Greywacke	5 (5)	8 (9)	11 (13)	24 (10)	17 (22)	8 (8)	48 (17)	3 (2)
Percent (by weight) of lithological type retained on 9.5mm sieve.								
Lithological Type.	Fan alluvium						Till	Twelve Mile delta
	1A	1B	8A	9A	9B	10A	11A	12.1
Quartz	26 (21)	28 (18)	14 (19)	8 (9)	20 (37)	23 (32)	50 (14)	34 (29)
Schist	65 (49)	58 (36)	76 (92)	82 (67)	58 (104)	70 (96)	10 (3)	60 (61)
Greywacke	9 (5)	14 (9)	10 (12)	10 (9)	21 (33)	7 (10)	40 (11)	5 (4)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Fan alluvium, till and Twelve Mile delta lithological analysis of sample retained on 19.0mm and 9.5mm sieve.

Percent (by weight) of lithological type retained on 4.75mm sieve.								
Lithological Type.	Fan alluvium						Till	Twelve Mile delta
	1A	1B	8A	9A	9B	10A	11A	12.1
Quartz	29 (91)	19 (40)	18 (54)	20 (68)	17 (60)	6 (22)	44 (114)	18 (70)
Schist	66 (184)	69 (130)	74 (207)	70 (184)	76 (233)	90 (252)	34 (96)	79 (332)
Greywacke	5 (9)	13 (20)	8 (14)	10 (22)	7 (18)	4 (8)	21 (38)	3 (7)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Fan alluvium, till and Twelve Mile delta lithological analysis of sample retained on 4.75mm sieve.

Percent (by weight) of lithology type retained on 37.5mm sieve.					
Scalped/crushed and all-in crushed fan alluvium.					
	12SC	14SC	15C	16C	17C
Quartz	0	0	0	0	0
Schist	100 (1)	100 (1)	41 (1)	100 (1)	31 (1)
Greywacke	0	0	59 (1)	0	69 (1)

Percent (by weight) of lithology type retained on 19.0mm sieve.					
Scalped/crushed and all-in crushed fan alluvium.					
	12SC	14SC	15C	16C	17C
Quartz	2 (2)	4 (9)	5 (13)	7 (7)	7 (25)
Schist	85 (68)	92 (184)	93 (213)	84 (169)	91 (205)
Greywacke	13 (8)	4 (10)	3 (9)	9 (7)	2 (5)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Crushed fan alluvium lithological analysis of sample retained on 37.5mm and 19.0mm sieve.

Percent (by weight) of lithology type retained on 9.5mm sieve.					
Scalped/crushed and all-in crushed fan alluvium.					
Lithological Type.	12SC	14SC	15C	16C	17C
Quartz	5 (4)	8 (13)	11 (13)	15 (33)	13 (17)
Schist	91 (83)	89 (148)	85 (95)	78 (179)	85 (98)
Greywacke	4 (9)	3 (3)	4 (6)	7 (17)	2 (2)
Percent (by weight) of lithology type retained on 4.75mm sieve.					
Scalped/crushed and all-in crushed fan alluvium.					
Lithological Type.	12SC	14SC	15C	16C	17C
Quartz	5 (14)	16 (48)	10 (16)	13 (56)	18 (57)
Schist	90 (250)	81 (280)	87 (199)	81 (324)	77 (239)
Greywacke	5 (11)	3 (9)	3 (5)	6 (22)	5 (6)

NB: numbers in brackets signify the amount of particles that result in the corresponding percentage.

Crushed fan alluvium lithological analysis of sample retained on 9.5mm and 4.75mm sieve.